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**NASA INDUSTRIAL APPLICATION CENTER**

University of Southern California

Denney Research Building, Third Floor Los Angeles, California 90007

(213) 741-6132

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ADVANCED TECHNOLOGY DISPLAY HOUSE

VOLUME 2

ENERGY SYSTEM DESIGN CONCEPTS

**Advanced Technology Display House**

**Vol. 2.**

**Energy System Design Concepts**

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**A. Preliminary Design Concept: Energy System**



ATH PROJECT  
PRELIMINARY DESIGN CONCEPT

ENERGY SYSTEM  
December 21, 1979

Residential Energy Demand

Obviously, energy required to run a single family dwelling is dependent on some highly variable factors such as building type and configuration, location, occupants life style, etc., etc. In spite of all the recent studies in this area there is not much conformity between them as to what constitutes a "typical" house, how much energy is needed (even in very round figures), or even in the energy units and definitions used. So comparisons are difficult. However, for the purposes of the preliminary design objectives of the ATH, the following figures were assembled based on whatever relevant data could be picked out of the reports surveyed and translated into a reasonably consistent picture.

"ALL ELECTRIC" SINGLE FAMILY HOUSE

Typical Annual Energy Use (KWh)

	<u>Los Angeles</u>	<u>Seattle</u>	<u>Phoenix</u>	<u>Denver</u>
Lighting	2,000	2,000	2,000	2,000
Appliances & Aux. Equip.	6,000	6,000	6,000	6,000
Water Heating	5,000	5,000	5,000	5,000
Air Conditioning	5,000	2,400	19,000	5,700
Space Heating	1,300	14,000	1,200	17,000
<u>Totals</u>	<u>19,300</u>	<u>29,400</u>	<u>33,200</u>	<u>35,700</u>

These "educated guesses" for four Western city areas are based on a comfortable lifestyle with the usual complement of appliances and household apparatus, including a heat pump for conditioning and heating.

The "typical" house is assumed to be built to current codes and standards, ie, tighter than pre 1974 standards but neither as tight nor as insulated as contemporary technology allows (due to persistent emphasis on first cost considerations over life cycle cost economics in the building industry).

The first three items (lighting, appliances, service water heating) are pretty much the same for all areas. Air conditioning and space heating are the items strongly influenced by regional climate. The essential problem is not the actual demand levels but the variations due to diurnal usage patterns for all items plus seasonal demand for the space heating and cooling. The resulting cyclic demand pattern will determine actual power capacities that must be provided for the house.

The other main complication with energy demand is the extreme spikes introduced mostly by motor startups. These short term transients are usually smoothed out for a utility line serving a number of houses. But for the individual house they can throw a 10kw spike on, say, a 1kw base load. This imposes some severe conditions for on-site generation and storage components.

### Demand Patterns for the ATH

Through design engineering and advanced technology applications the ATH will enable substantial reductions in "normal" energy consumed by the house equipment and systems. Also the designs should encourage further reductions by inhibiting the extremely wasteful practices ingrained during the era of cheap energy. The following are minimal design objectives.

- 1) Very substantial reductions (up to 60-70%) in building energy demand can be achieved with passive design methods. However, most of these methods entail the use of heavy mass for thermal storage and directed flows (as in Trombe walls for instance.) Heavy solid masses may not be compatible with the light structural/modular/flexible design approach desired for the ATH, although water or eutectic salt based systems may be feasible since conceivably they could be easily pumped out to enable easier arrangement than allowed by permanent concrete or rock installations.

However, imaginative arrangement of interior spaces and high levels of insulation should cut atmospheric conditioning energy by 30% for heating and by 10% for cooling loads.

- 2) Infiltration and ventilation air exchange accounts for about 55% of the heating load and 42% of the cooling load. A very tight house with controlled inlet and exhaust air systems incorporating thermal exchanges can recover at least 35% of the heating losses and 20% of the cooling losses. These figures suggest advanced house design engineering will cut heating loads by  $0.55 \times 0.35 = 19\%$  and cooling loads by  $0.42 \times 0.20 = 8\%$ .
- 3) Automatic thermostat set backs can reduce energy usage without imposing any hardships on residents. (In fact, slightly cooler atmosphere may be healthier). In the heating mode, lowering interior temperatures from  $75^{\circ}\text{F}$  to  $68^{\circ}\text{F}$  plus night time setback to  $60^{\circ}\text{F}$  can reduce energy demand by 10%. In the cooling mode, if interior air goes to  $80^{\circ}\text{F}$  @ 60% humidity from the normal  $75^{\circ}\text{F}$  @ 50% humidity the energy load is reduced by 15%.
- 4) Typically, service hot water is maintained at  $140\text{--}150^{\circ}\text{F}$  to accommodate the intermittent needs of dishwashers and dryers. The bulk of hot water needs require  $105\text{--}115^{\circ}\text{F}$ . Keeping hot water at  $110^{\circ}\text{F}$ , using local heat boosters for the washers and dryers, and increasing system insulation will cut hot water energy loads by 10%. In addition sensible reductions in hot water use by flow reduction at showers and other outlets can cut heat energy waste by a further 15%.

- 5) Advanced technology motors, controls and construction of appliances and service equipment can cut appliance energy waste by 50%.
- 6) Lighting loads can be cut at least 40% using advanced design and technology options.

Applying the above assumptions to the typical total energy requirements for the ATH gives the following:

**Base Energy Demand for ATH (kwh/yr)**

	<u>Los Angeles</u>	<u>Seattle</u>	<u>Phoenix</u>	<u>Denver</u>
Lighting	1,200	1,200	1,200	1,200
Appliances & Aux.	3,000	3,000	3,000	3,000
Water Heating	3,800	3,800	3,800	3,800
Air Conditioning	3,500	1,680	13,300	3,990
Space Heating	730	7,840	670	9,520
<u>Totals</u>	<u>12,230</u>	<u>17,520</u>	<u>21,970</u>	<u>21,510</u>
% of "Normal" load	63%	60%	66%	60%

The above results are derived solely from basic systems technology improvements and do not include any allowances for on-site energy generation.

As mentioned previously, the crucial problem of energy supply is not aggregate demand but diurnal, seasonal peaking and frequent high wattage transients. The most significant effect of the design measures discussed above may well be the smoothing of the demand peaks and the spiky transient profile. Evaluation of these benefits will be made as specific design engineering for the ATH emerges.

Another interesting possibility is the psychological effect of residents taking a more proprietary interest in on-site generated energy, compared with the utility services. This could lead to further energy economics and reduced waste especially if encouraged by judiciously located power meters and automatic weekly "energy audit" print-outs from the home management computer systems. Simple measures, such as reducing time refrigerator doors are held open for instance, may be perceived as more meaningful in the ATH environment and have more impact than impersonal exhortations for conservation of "anonymous" public utility power. No references on this psychological effect was found in the literature surveyed (though it was not specifically sought).

Counteracting some of the energy reductions will be additional electrical loads for other systems and controls, communications/computer equipment, etc. Demand for these items should not be excessive and will be included in detailed evaluations as the ATH design specifics develop. An exception would be if the ATH included facilities for recharging electric vehicles which would obviously impose greater aggregate loads on the energy system, although it might fit well into the peak/valley demand profile so that overall power capacity may not be greatly affected.

A useful compendium of passive energy design consideration is attached as Appendix I.

### Preliminary On-Site Energy Concepts

The various configurations of direct solar thermal devices have two principle advantages.

- 1) Efficient energy transfer for the space heating and hot water heating functions, which are major energy users in some, though not all, locations. (Refer to basic residential demand table previously).
- 2) There is much more operating experience with the solar thermal systems.

Also there are some drawbacks with all types of solar thermal systems:

- 1) Technology for solar heat driven cooling systems is complex and not highly developed. This is a serious problem for locations where air conditioning loads are dominant.
- 2) Installation of thermal systems involve non-trivial problems of fluid plumbing or air ducting which may constrain or otherwise influence house structural designs and layouts. Also these systems may be somewhat restrictive for the flexible modular formats to be strived for in the ATH.

According to current and anticipated technology developments, photovoltaic (PV) systems are a more attractive option for the ATH for the following reasons.

- 1) The house requires electrical power anyway.
- 2) Electricity is a clean, "high grade" form of energy which can be applied to any residential power requirement.
- 3) PV systems are potentially easier to install and subject to fewer maintenance problems.
- 4) PV systems are easier to plug together in various sizes and arrangements of arrays.
- 5) Hybrid systems may be considered which advantageously employ electric and heat energy from the same cell array.
- 6) The above reasons combine to make PV systems more suited to the ATH modular concepts.
- 7) PV systems are more in the spirit of the ATH project which is to anticipate and explore advanced technology options.

Since 1974 there have been numerous in-depth concept evaluation studies of PV systems for residential applications. Prime participants in these studies included G.E., Westinghouse, TRW, Systems, Martin Marietta, Bechtel. In most cases however, these studies were constrained in scope to consider only available technology and components and apply them to conventional demand patterns. As a result, they all reached the same basic conclusions:

- Only lead-acid battery banks considered feasible for on-site storage.
- Conditioning of the PV array DC output to match 110 VAC, 60 cycle line power.
- Not feasible to achieve demand/supply match for 100% on-site power generation.
- The preferred system (a) had no on-site storage, (b) provided DC power conditioning to line power standards and (c) fed back excess on-site power into the utility line.

Advantages claimed were:

- 1) Simplicity of direct tie-in to utility power.
- 2) Use of conventional electrical systems and wiring.
- 3) Full use of total output from the PV array.

However, there were many difficulties:

- 1) Systems required DC-AC conversion with significant power loss to the inverters.
- 2) Inverters had to handle up to 10 kw demand peaks (for transients) to prevent motor stalls.
- 3) Inverters, besides wasting some 15% of available energy in efficiency losses, are rotary machines and subject to maintenance problems. (Bechtel suggested semi-conductor power inverters as an alternative to the rotary inverters). Adequate equipment was not readily available off-the-shelf and was expensive.
- 4) To supply input to the inverter, battery banks had to be sized to deliver at least 120 volt DC.
- 5) Other power hungry regulating circuitry was needed.
- 6) PV arrays were constrained to deliver up to 144 volt power to the batteries to meet changing requirements.

7) Battery requirements ran as high as

- 10 kw power
- 30 kwh of storage
- 300 volt output
- 500 amp hour capacity
- daily duty cycles with varying depth of discharge.

This can be a high maintenance item with considerable danger potential due to hydrogen evolution, acid leakage, etc.

8) There are problems of feeding power into a utility line such as:

- reliability and quality of power matching.
- legal and institutional problems.
- rate/rebate charge

Overall, though technically feasible, significant generation of PV energy on-site did not seem reasonable (at the time) with existing or immediately foreseeable technology (even allowing for on-schedule cost reductions for the PV arrays).

In retrospect, there are some curious aspects to these previous studies. In one instance, for example, a conceptual system for a house in Phoenix could displace up to 93% of normal utility power requirements with a PV array. Yet the array output was converted to 120 VAC via an inverter with maximum efficiency of 88% (probably more like 80%) and at high cost (several thousand dollars). The possibility of directly using the DC output from the array within the house, and rectifying the line power (much less difficult) for occasional back up, was not considered.

In light of current technology developments and in keeping with the future orientation of the ATH it is appropriate to investigate the following configuration for on-site energy generation and storage.

- 1) An optimally sized PV array to deliver at least 80% of house total energy needs. Heat pumps used for primary space heating and conditioning.
- 2) House and systems wired for DC power to directly use PV output and avoid expensive conversion. (DC current/voltage standards to be determined).
- 3) Use of a REDOX DC power storage system.  
(A description of the REDOX concept is attached.)

- 4) Rectification of the AC line power to provide back up power to the house system as required. (Preferably under computer control to enable off peak changing from the AC line).
- 5) As appropriate, use array cooling system to increase PV efficiency and provide thermal heat for house use. (ie. a hybrid system).  
There are a number of implications to be explored in this concept.

Use of DC house power shouldn't be difficult (in an earlier age that's all there was). For resistive loads (ie heaters, incandescent lamps, etc.) there may be significant overall gains in power efficiency and component life compared to using AC power. Appliances and motor driven equipment would have to be refitted with available DC motors. Timers, clocks and regulators which depend on a stable 60 cycle power source would be replaced with quartz crystal mechanisms. Some DC power could be conditioned to AC if absolutely necessary using the 60 cycle line as a reference. This might be useful for fluorescent lighting for instance, but an initial impression is that such a step would be an unjustifiable complication compared with any likely benefits.

Irrespective of whether a REDOX unit or lead-acid cells were used for storage, using DC house power removes some severe constraints on the PV array/battery design interface since it is not necessary to supply voltage and power at levels needed for conversion to 120 VAC line power. House voltage can be optimized to suit the dynamics of the voltage/current curves of the array and the charge/discharge characteristics of the batteries.

However, a REDOX unit is likely to have many advantages;

- 1) More flexibility in sizing charge capacity and power supply to suit the combined needs of the PV array and house energy demand.
- 2) Longer life expectancy (20 yrs. v. 5-7 for the lead acid cells).
- 3) Lower cost (ultimately).
- 4) Low maintenance requirements (built in, automatic trimming and rebalancing).
- 5) Much safer system (no hydrogen evolution and no strong acids used).
- 6) Higher energy efficiencies over each in/out charge cycle.
- 7) No problems due to fast switching from charge to discharge (eg. momentary cloud cover interrupting insolation of the array).
- 8) Good response to short term transient demand spikes.

A private phone conversation with an engineer on the REDOX program indicates that a suitably sized unit for the ATH could be possible within 18 months-2 years. Depending on further analysis and expert opinions (to be gathered)

it may be advisable to urge an accelerated effort in view of the superb opportunity to demonstrate and test the REDOX principle in the ATH. If this is not feasible, a REDOX could be installed as large as available at the time and backed up with a "black box" of conventional batteries.

Another prime advantage in using either REDOX or conventional batteries is to use the storage bank as a load levelling device for utility power. That is, computer controlled house load management would enable off peak, night time charging instead of using utility back up power during the day. This will be important for installations located in areas where mean isolation levels cannot support house energy demands.

At this point it does not seem appropriate to consider feeding back excess power to a utility line unless unusual circumstances prevail. The institutional problems raised are interesting and challenging but involve issues largely beyond the control or scope of the ATH project. As such they should rightfully be left to the analysis of much larger, regional systems. Nonetheless, knowledge and experience gained from the ATH sized system will unquestionable be of great value to such larger scale analyses.

Since it would be necessary to engineer a complement of appliances and machinery to accommodate the DC house power in the ATH it would be beneficial to explore the possibility of reducing transient peak loads from motor start-ups. For instance, is it feasible to program motor starts under no load conditions then gradually apply the load via a controlled clutch device? Or will a REDOX unit make this sophistication unnecessary?

#### Addendum

The concept of the ATH involves a high degree of self-sufficiency in power, water, and sewage systems. This is in direct contrast to the highly centralized utility systems concepts in place today. It is becoming more evident that in future years the optimum point will be found somewhere between these two extremes. Though perhaps technically feasible, it is not necessarily desirable or economic to establish entirely independent house units. And in-place central utility systems, which must yet be amortized over many more years, are subject to unacceptable inefficiencies. (For instance, consider that only one-third or less of a given fuel energy content reaches the house as electric power). The ultimate technological solution is likely to be some form of Modular Integrated Utility System (MIUS) which combines utility functions of water conditioning, sewage and waste treatment, power generation in one unit serving a local community. Ultimately, it will be interesting to develop a community test site on the scale of Reston, Virginia, for instance. In the meantime, the ATH will provide valuable data for assessing the merits of these concepts. It is on such a scale that energy generation alternatives such as wind power, gas generators, etc. are likely to come into their own. For the foreseeable future these alternatives do not appear to fit well into individual urban/suburban house units, (with obvious exceptions in rural areas for example). Wind power, in particular, is very dependent on local terrain and microclimate. The generators need clear air space as much as 40 ft. above surrounding objects which makes them visually obtrusive. Also, they are much more efficient at large diameter rotor sizes. Therefore, these systems do not seem to provide a prime option for the ATH at this time.





- b. Use impermeable exterior surface materials.
- c. Reduce crackage area around doors, windows, etc., to a minimum.
- d. Provide all external doors with weather stripping.
- e. Where operable windows are used, provide them with sealing gaskets and cam latches.
- f. Locate building entrances on downwind side and provide wind break.
- g. Provide all entrances with vestibules; where vestibules are not used, provide revolving doors.
- h. Provide vestibules with self-closing weather-stripped doors to isolate them from the stairwells and elevator shafts.
- i. Seal all vertical shafts.
- j. Locate ventilation louvers on downwind side of building and provide wind breaks.
- k. Provide break at intermediate points of elevator shafts and stairwells for tall buildings.
22. Provide wind protection by using fins, recesses, etc., for any exposed surface having a U value greater than 0.5.
23. Do not heat parking garages.
24. Consider the amount of energy required for the protection of materials and their transport on a life-cycle energy usage.
25. Consider the use of the insulation type which can be most efficiently applied to optimize the thermal resistance of the wall or roof; for example, some types of insulation are difficult to install without voids or shrinkage.
26. Protect insulation from moisture originating outdoors, since volume decreases when wet. Use insulation with low water absorption and one which dries out quickly and regains its original thermal performance after being wet.
27. Where sloping roofs are used, face them to south for greatest heat gain benefit in the wintertime.
28. To reduce heat loss from windows, consider one or more of the following:
- Use minimum ratio of window area to wall area.
  - Use double glazing.
  - Use triple glazing.
  - Use double reflective glazing.
  - Use minimum percentage of the double glazing on the north wall.
  - Manipulate east and west walls so that windows face south.
  - Allow direct sun on windows November through March.
  - Avoid window frames that form a thermal bridge.
  - Use operable thermal shutters which decrease the composite U value to 0.1.
29. To reduce heat gains through windows, consider the following:
- Use minimum ratio of window area to wall area.
  - Use double glazing.
  - Use triple glazing.
  - Use double reflective glazing.
  - Use minimum percentage of double glazing on the south wall.
  - Shade windows from direct sun April through October.
30. To take advantage of natural daylight within the building and reduce electrical energy consumption, consider the following:
- Increase window size but do not exceed the point where yearly energy consumption, due to heat gains and losses, exceeds the saving made by using natural light.
  - Locate windows high in wall to increase reflection from ceiling, but reduce glare effect on occupants.
  - Control glare with translucent draperies operated by photo cells.
  - Provide exterior shades that eliminate direct sunlight, but reflect light into occupied spaces.
  - Slope vertical wall surfaces so that windows are self shading and walls below act as light reflectors.

A4 D2	A1 E2	A3 D1	C4 F
A4 D2	A1 E2	A3 D1	C4 F
A4	A1	B4	C2
.	.	.	.
A1	A2	B1	C4
A4 A1 A2 A3	B4 B1 B2 B3	C4 C1 C2 C3	
D1 D2	E1 E2	F F	
C2 C1 C3 C4 F	B2 B1 B2 B4 E	A2 A2 A3 A4 D	

- f. Use clear glazing. Reflective or heat absorbing films reduce the quantity of natural light transmitted through the window.
31. To allow the use of natural light in cold zones where heat losses are high energy users, consider operable thermal barriers.
32. Use permanently sealed windows to reduce infiltration in climatic zones where this is a large energy user.
33. Where codes of regulations require operable windows and infiltration is undesirable, use windows that close against a sealing gasket.
34. In climatic zones where outdoor air conditions are suitable for natural ventilation for a major part of the year, provide operable windows.
35. In climatic zones where outdoor air conditions are close to desired indoor conditions for a major portion of the year, consider the following:
- Adjust building orientation and configuration to take advantage of prevailing winds.
  - Use operable windows to control ingress and egress of air through the building.
  - Adjust the configuration of the building to allow natural cross ventilation through occupied spaces.
  - Use stack effect in vertical shafts, stairwells, etc., to promote natural air flow through the building.

## PLANNING

- Group services rooms as a buffer and locate at the north wall to reduce heat loss or the south wall to reduce heat gain, whichever is the greatest yearly energy user.
- Use corridors as heat transfer buffers and locate against external walls.
- Locate rooms with high process heat gain (computer rooms) against outside surfaces that have the highest exposure loss.
- Landscaped open planning allows excess heat from interior spaces to transfer to perimeter spaces which have a heat loss.
- Rooms can be grouped in such a manner that the same ventilating air can be used more than once, by operating in cascade through spaces in decreasing order of priority, i.e., office-corridor-toilet.
- Reduced ceiling heights reduce the exposed surface area and the enclosed volume. They also increase illumination effectiveness.
- Increased density of occupants (less gross floor area per person) reduces the overall size of the building and yearly energy consumption per capita.
- Spaces of similar function located adjacent to each other on the same floor reduce the use of elevators.
- Offices frequented by the general public located on the ground floor reduce elevator use.
- Equipment rooms located on the roof reduce unwanted heat gain and heat loss through the surface. They can also allow more direct duct and pipe runs reducing power requirements.
- Windows planned to make beneficial use of winter sunshine should be positioned to allow occupants the opportunity of moving out of the direct sun radiation.
- Deep ceiling voids allow the use of larger duct sizes with low pressure drop and reduce HVAC requirements.
- Processes that have temperature and humidity requirements different from normal physiological needs should be grouped together and served by one common system.
- Open planning allows more effective use of lighting fixtures. The reduced area of partitioned walls decreases the light absorption.

Priority			
1	2	3	N/A
A4 D1	A1 D2	A3 E1	C2 F
A4 D1 A4	A1 D2 A1	A3 E1 A3	C2 F C7
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
A4 D1	A3 D2	B4 E1	C2
.	.	.	.
.	.	.	.
.	.	.	.

- 15. Judicious use of reflective surfaces such as sloping white ceilings can enhance the effect of natural lighting and increase the yearly energy saved.**

## VENTILATION AND INFILTRATION

1. To minimize infiltration, balance mechanical ventilation so that supply air quantity equals or exceeds exhaust air quantity.
2. Take credit for infiltration as part of the outdoor air requirements for the building occupants and reduce mechanical ventilation accordingly.
3. Reduce C.F.M./occupant outdoor air requirements to the minimum considering the task they are performing, room volume and periods of occupancy.
4. If odor removal requires more than 2,000 cubic feet per minute exhaust and a corresponding introduction of outdoor air, consider recirculating through activated carbon filter.
5. Where outdoor conditions are close to but less than indoor conditions for major periods of the year, and the air is clean and free from offensive odors, consider the use of natural ventilation when yearly energy trade-offs with other systems are favorable.
6. Exchange heat between outdoor air, intake and exhaust air by using heat pipes, thermal wheels, run-around systems, etc.
7. In areas subjected to high humidities, consider latent heat exchange in addition to sensible.
8. Provide selective ventilation as needed; i.e., 5 cubic feet per minute/occupant for general areas and increased volumes for areas of heavy smoking or odor control.
9. Transfer air from "clean" areas to more contaminated areas (toilet rooms, heavy smoking areas) rather than supply fresh air to all areas regardless of function.
10. Provide controls to shut down all air systems at night and weekends except when used for economizer cycle cooling. Reduce the energy required to heat or cool ventilation air from outdoor conditions to interior design conditions by considering the following:
  - a. Reduce indoor air temperature setting in winter and increase in summer.
  - b. Provide outdoor air direct to perimeter of exhaust hoods in kitchens, laboratories, etc. Do not cool this air in summer or heat over 50 degrees F. in winter.

Priority	N/A									
	A2 D2									
	C3 E2									
	C1 E1									
3	C	F	C	F	C	F	C	F	C	F
2	B	E	B	E	B	E	B	E	B	E
1	A	D	A	D	A	D	A	D	A	D

## HEATING, VENTILATION AND AIRCONDITIONING

1. Use outdoor air for sensible cooling whenever conditions permit and when "recaptured" heat cannot be stored.
2. Use adiabatic saturation to reduce temperature of hot, dry air to extend the period of time when "free cooling" can be used.
3. In the summer when the outdoor air temperature at night is lower than indoor temperature, use full outdoor air ventilation to remove excess heat and precool structure.
4. In principle, select the air handling system which operates at the lowest possible air velocity and static pressure. Consider high pressure systems only when other trade-offs such as reduced building size are an overriding factor.
5. To enhance the possibility of using waste heat from other systems, design air handling systems to circulate sufficient air to enable cooling loads to be met by a 60 degree F. air supply temperature and heating loads to be met by a 90 degree F. air temperature.

Priority	N/A			
	1	2	3	
	.			
	D1	E1	F	
	D1	E1	F	
	.			
	.			

6. Design HVAC systems so that the maximum possible proportion of heat gain to a space can be treated as an equipment load, not as a room load.
7. Schedule air delivery so that exhaust from primary spaces (offices) can be used to heat or cool secondary spaces (corridors).
8. Exhaust air from center zone through the lighting fixtures and use this warmed exhaust air to heat perimeter zones.
9. Design HVAC systems so that they do not heat and cool air simultaneously.
10. To reduce fan horsepower, consider the following:
  - a. Design duct systems for low pressure loss.
  - b. Use high efficiency fans.
  - c. Use low pressure loss filters concomitant with contaminant removal.
11. Use one common air coil for both heating and cooling. Reduce or eliminate air leakage from duct work.
12. Limit the use of re-heat to a maximum of 10 percent of gross floor area and then only consider its use for areas that have atypical fluctuating internal loads, such as conference rooms.
13. Design chilled water systems to operate with as high a supply temperature as possible—suggested goal: 50 degrees F. (This allows higher suction temperatures at the chiller with increased operating efficiency.)
14. Use modular pumps to give varying flows that can match varying loads.
15. Select high efficiency pumps that match load. Do not oversize.
16. Design piping systems for low pressure loss and select routes and locate equipment to give shortest pipe runs.
17. Adopt as large a temperature differential as possible for chilled water systems and hot water heating systems.
18. Consider operating chillers in series to increase efficiency.
19. Select chillers that can operate over a wide range of condensing temperatures and then consider the following:
  - a. Use double bundle condensers to capture waste heat at high condensing temperatures and use directly for heating or store for later use.
  - b. When waste heat cannot be either used directly or stored, then operate chiller at lowest condensing temperature compatible with ambient outdoor conditions.
20. Consider chilled water storage systems to allow chillers to operate at night when condensing temperatures are lowest.
21. Consider the use of double bundle evaporators so that chillers can be used as heat pumps to upgrade stored heat for use in unoccupied periods.
22. Consider the use of gas or diesel engine drive for chillers and large items of ancillary equipment and collect and use waste heat for absorption cooling, heating, and/or domestic hot water.
23. Locate cooling towers or evaporative coolers so that induced air movement can be used to provide or supplement garage exhaust ventilation.
24. Use modular boilers for heating and select units so that each module operates at optimum efficiency.
25. Extract waste heat from boiler flue gas by extending surface coils or heat pipes.
26. Select boilers that operate at the lowest practicable supply temperature while avoiding condensation within the furnace.
27. Use unitary water/air heat pumps that transport heat energy from zone to zone via a common hydronic loop.
28. Consider the use of thermal storage in combination with unit heat pumps and a hydronic loop so that excess heat during the day can be captured and stored for use at night.
29. Consider the use of heat pumps both water/air and air/air. If a continuing source of low-grade heat exists near the building, such as lake, river, etc.

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OF POOR QUALITY



10. Provide suggestions to GSA for analysis of tasks to increase use of high contrast material which requires less illumination.
11. Select furniture and interior appointments that do not have glossy surfaces or give specular reflections.
12. Use light spills from characteristic areas to illuminate non-characteristic areas.
13. Consider use of greater contrast between tasks and background lighting, such as 8 to 1 and 10 to 1.
14. Consider washers and special illumination for features such as plants, murals, etc., in place of overhead space lighting to maintain proper contrast ratios.
15. For horizontal tasks or duties, consider fixtures whose main light component is oblique and then locate for maximum ESI footcandles on task.
16. Consider using 250 watt mercury vapor lamps and metal-halide lamps in place of 500 watt incandescent lamps for special applications.
17. Use lamps with higher lumens per watt input, such as:
  - a. One 8-foot fluorescent lamp versus two 4-foot lamps.
  - b. One 4-foot fluorescent lamp versus two 2-foot lamps.
  - c. U-tube lamps versus two individual lamps.
  - d. Fluorescent lamps in place of all incandescent lamps except for very close task lighting, such as a typewriter paper holder.
18. Use high utilization and maintenance factors in design calculations and instruct users to keep fixtures clean and change lamps earlier.
19. Avoid decorative flood-lighting and display lighting.
20. Direct exterior security lighting at entrances and avoid illuminating large areas adjacent to building.
21. Consider switches actuated by intruder devices rather than permanently lit security lighting.
22. If already available, use street lighting for security purposes.
23. Reduce lighting requirements for hazards by:
  - a. Using light fixtures close to and focused on hazard.
  - b. Increasing contrast of hazard; i.e., paint stair treads and risers white with black nosing.
24. Consider the following methods of coping with code requirements:
  - a. Obtaining variance from existing codes.
  - b. Changing codes to just fulfill health and safety functions of lighting by varying the qualitative and quantitative requirements to specific application.
25. Consider the use of a total energy system integrated with all other systems.
26. Where steam is available, use turbine drive for large items of equipment.
27. Use heat pumps in place of electric resistance heating and take advantage of the favorable coefficient of performance.
28. Match motor sizes to equipment shaft power requirements and select to operate at the most efficient point.
29. Maintain power factor as close to unity as possible.
30. Minimize power losses in distribution system by:
  - a. Reducing length of cable runs.
  - b. Increasing conductor size within limits indicated by life-cycle costing.
  - c. Use high voltage distribution within the building.
31. Match characteristics of electric motors to the characteristics of the driven machine.
32. Design and select machinery to start in an unloaded condition to reduce starting torque requirements. (For example, start pumps against closed valves.)
33. Use direct drive whenever possible to eliminate drive train losses.
34. Use high efficiency transformers (these are good candidates for life-cycle costing).
35. Use liquid-cooled transformers and captive waste heat for beneficial use in other systems.
36. In canteen kitchens, use gas for cooking rather than electricity.
37. Use conventional ovens rather than self-cleaning type.

[illegible]

30. Consider the direct use of solar energy via a system of collectors for heating in winter and absorption cooling in summer.
  31. Minimize requirements for snow melting to those that are absolutely necessary and, where possible, use waste heat for this service.
  32. Provide all outside air dampers with accurate position indicators and insure that dampers are air-tight when closed.
  33. If electric heating is contemplated, consider the use of heat pumps in place of direct resistance heating; by comparison they consume one-third of the energy per unit output.
  34. Consider the use of spot heating and/or cooling in spaces having large volume and low occupancy.
  35. Use electric ignition in place of gas pilots for gas burners.
  36. Consider the use of a total energy system if the life-cycle costs are favorable.
- ## LIGHTING AND POWER
1. a. Use natural illumination in areas where effective when a net energy conservation gain is possible vis-a-vis heating and cooling loads.  
b. Provide exterior reflectors at windows for more effective internal illumination.
  2. Consider a selective lighting system in regard to the following:
    - a. Reduce the wattage required for each specific task by review of user needs and method of providing illumination.
    - b. Consider only the amount of illumination required for the specific task considering the duration and character and user performance required as per design criteria.
    - c. Group similar task together for optimum conservation of energy per floor.
    - d. Design switch circuits to permit turning off unused and unnecessary light.
    - e. Illuminate tasks with fixtures built into furniture and maintain low intensity lighting elsewhere.
    - f. Consider the use of polarized lenses to improve quality of lighting at tasks.
    - g. Provide timers to automatically turn off lights in remote or little-used areas.
    - h. Use multilevel ballasts to permit varying the lumen output for fixtures by adding or removing lamps when tasks are changed in location or requirements.
    - i. Arrange electrical systems to accommodate relocatable luminaires which can be removed to suit changing furniture layouts.
    - j. Consider the use of ballasts which can accommodate sodium metalhalide bulbs interchangeably with other, lamps.
  3. Consider the use of high frequency lighting to reduce wattage per lumen output. Additional benefits are reduced ballast heat loss into the room and longer lamp life.
  4. Consider the use of landscape office planning to improve lighting efficiency. Approximately 25 percent less wattage per foot-candles on task for open planning versus partitions.
  5. Consider the use of light colors for walls, floors and ceilings to increase reflectance, but avoid specular reflections.
  6. Lower the ceilings or mounting height of luminaires to increase level of illumination with less wattage.
  7. Consider dry heat-of-light systems to improve lamp performance and reduce heat gain to space.
  8. Consider wet heat-of-light system to improve lamp performance and reduce heat gain to space and refrigeration load.
  9. Use fixtures that give high contrast rendition factor at task.

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In canteen kitchens, use gas for cooking rather than electricity.  
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# REDOX

## NASA

National Aeronautics and  
Space Administration

Lewis Research Center

A unique energy-storage system called REDOX,\* developed at the NASA Lewis Research Center, Cleveland, Ohio under a program jointly funded by the U.S. Department of Energy and NASA, offers the promise of major cost reductions in the storing of electrical energy.

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\*REDOX is an acronym standing for Reduction Oxidation, a term commonly used in battery technology.

REDOX systems in the kilowatt range can soon contribute to speeding the growth of solar electric (photovoltaic) and wind-energy systems where the cost of electrical storage has been a major drawback. (Storage is necessary for the times the sun isn't shining or the wind isn't blowing.) At one-third the cost of conventional lead-acid storage battery systems now in use, the REDOX battery system will make solar electric



200-watt REDOX DEMONSTRATION  
SYSTEM IN ASSEMBLY STAGE

ORIGINAL PAGE IS  
OF POOR QUALITY

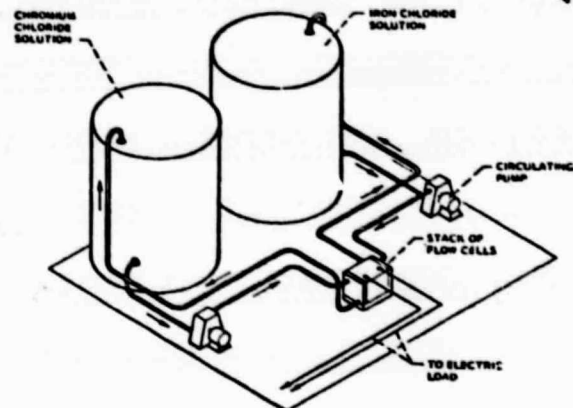
and wind-energy units much more practical and hasten their contribution to our nation's energy supply.

For utilities, the new NASA system could be scaled up in the next several years to provide electric power companies with an efficient means of load leveling - the storing of thousands of kilowatt-hours of energy during low demand periods for use later during periods of maximum power consumption.

Economical, efficient energy storage should eliminate the need for relatively expensive and less efficient standby generation equipment. Since standby generators are usually oil fueled, not to use them would help ease the pressure on this critical energy source.

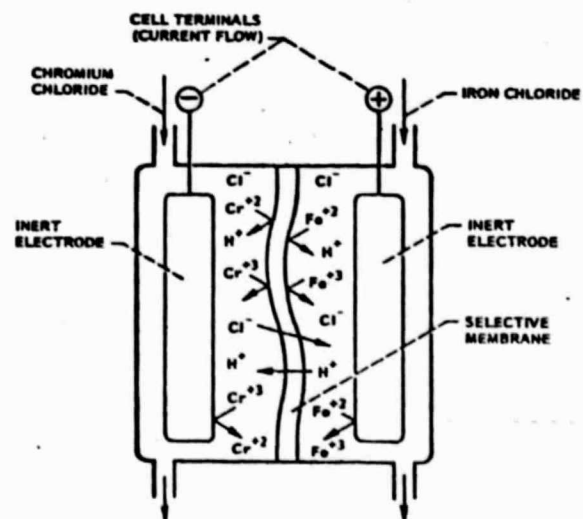
#### HOW REDOX WORKS

The heart of the REDOX system is a combination or "stack" of flow cells. Chemical energy is converted into electrical energy when two reactant fluids - chromium chloride and iron chloride - are pumped through the stack. In each flow cell, the fluids are kept separate by a special membrane developed for NASA by Ionics Inc., Watertown, Massachusetts. The membrane prevents chromium ions in one fluid from mixing with iron ions in the other fluid.



**TYPICAL REDOX STORAGE SYSTEM**

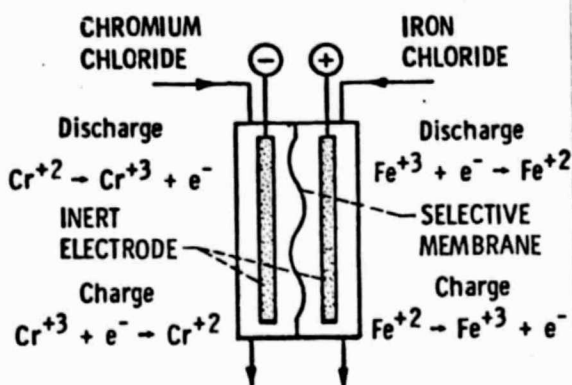
Smaller chlorine and hydrogen ions in the fluids, however, can pass freely through the membrane and transfer electric charge, producing a net flow of electric current through two inert carbon electrodes.



**REDOX FLOW CELL**

As the fluids circulate through the stack and electrical energy is withdrawn from the system at the external connections to the electrodes, the net electrochemical energy in each fluid is depleted until the system is fully discharged. To recharge, the fluids are simply pumped through the stack again but with electrical energy supplied from an outside source.

The basic electrochemical process in the REDOX system is not new; it is a simple reversible reaction known to high-school chemistry students. When electricity is being generated, chromous ions produce electrons and are oxidized to chromic ions. Ferric ions accept electrons and are reduced to ferrous ions. The process is reversed when the system is recharged.



BASIC ELECTROCHEMICAL PROCESS

The basic reactants can be used indefinitely. Only 1 percent of the system's energy is consumed in operating the circulating pumps, and 75 percent of the energy used to charge the system is returned on discharge, an efficiency comparable to conventional batteries.

### REDOX VS LEAD-ACID BATTERIES

The lead-acid battery was devised over a century ago, yet the chemical and physical details of its operation are still not fully understood. During recharge, the solid lead compounds on the battery electrodes do not always return completely to their previously charged state and condition, and some lead solids fall away from the electrodes. This loss of active material means a permanent deterioration in the battery's electrical capacity, and ultimately the battery is ruined.

In the REDOX battery, there are no solid compounds formed. Flow of reactant fluids is uniform through all cells that make up the battery. The life-limiting component is the membrane material separating the reactant fluids. Based on accelerated tests, NASA Lewis estimates the useful life of its present membrane materials at 20 to 30 years.

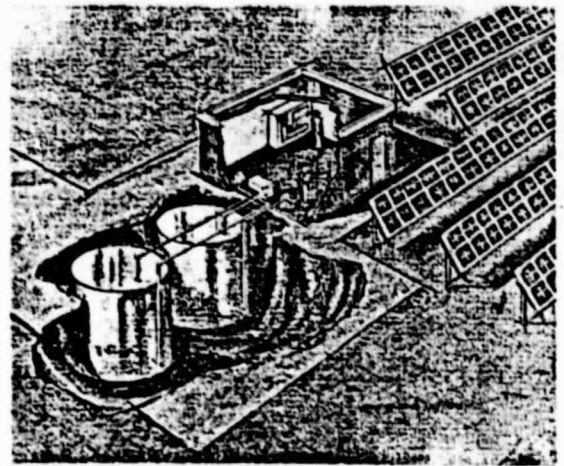
Another important technical advantage over lead-acid batteries is the ability to easily monitor and correct at the system level for changes in output voltage and total storage capacity without interrupting system operation. Best of all is the flexibility to size the stack and storage tanks independently to yield the best system characteristics. Stack size and number are chosen for the power (watts) to be delivered at any one time, and storage tanks are sized for the energy (watt-hours) needed for the time period between recharge cycles which can be days, weeks or even months.

#### **WHY UTILITIES ARE INTERESTED IN REDOX**

The benefits of REDOX systems for decentralized solar electric and wind-energy systems are simple to explain. These systems are fairly small in scale, and are usually isolated from utility power lines. REDOX systems would offer a one-for-one replacement for present lead-acid storage systems at greatly reduced costs.

Utilities are interested in REDOX because it would permit efficient load leveling, as stated before. Other storage schemes to date are too site specific and costly. As an illustration, some utilities have created energy storage by using

off-hour excess electrical capacity to pump water into elevated reservoirs and then regenerating power hydroelectrically with this water to supplement capacity during peak demand periods. Another possibility is to fill underground caverns with compressed gas that can drive turbogenerators when needed.



**10 kilowatt - 500 kilowatt-hour REDOX SYSTEM SOLAR ELECTRIC APPLICATION**

Both schemes require large capital investments. Many utilities don't have the right terrain, a 300-foot change in elevation for pumped hydro, for example, and very few have access to caverns. Also, if the storage is remote from the primary generation facilities, a new and costly major transmission line will be necessary. Furthermore, transmission-line power losses can be

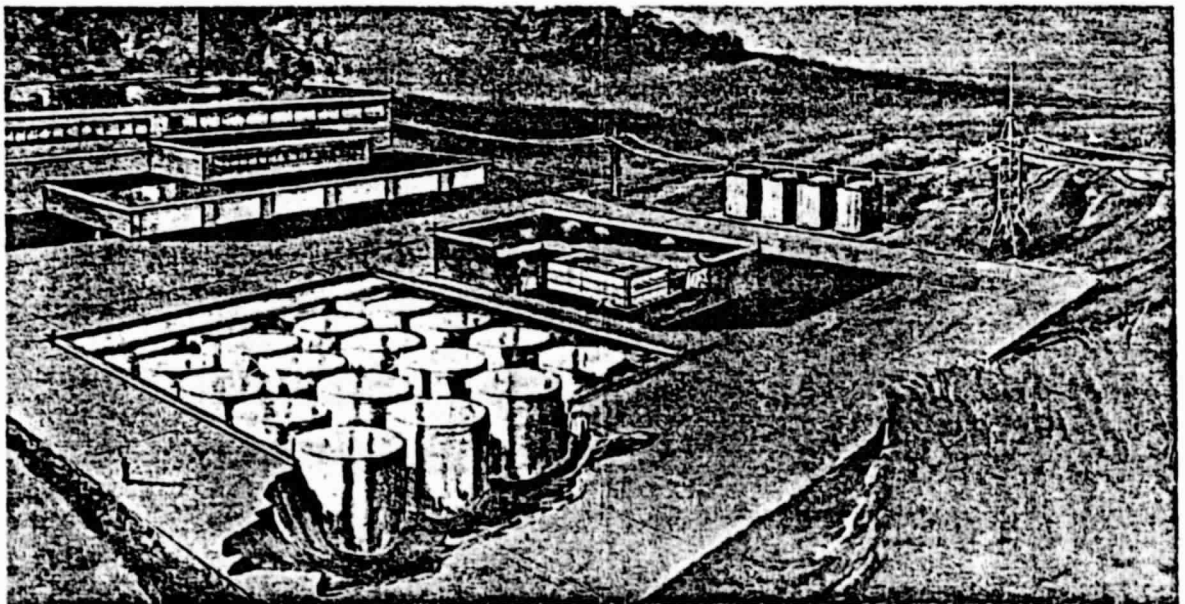


as much as 10 percent when electricity is "shipped" more than 75 miles.

Another solution is to locate smaller power storage facilities at several regional utility substations. This way, peak demands can be met locally, increasing the utility's power-delivering ability without upgrading its transmission lines. REDOX would be ideal for this application. Utilities speak of savings from decentralized power as a "transmission credit"; the savings from not needing to upgrade transmission lines pays for the costs of adding dispersed energy storage.

An energy storage system like REDOX would be of greatest value to utilities that generate power from coal or nuclear energy. These units operate most efficiently at a steady output or base load, and they generate the cheapest electricity other than hydroelectric systems. REDOX energy storage may also help small metropolitan systems that purchase much of their power at complex rates dependent on peak demand. By purchasing power at nonpeak rates and storing it, they could reduce their costs.

In summary, REDOX may indeed be expected to have a major effect on how our nation uses electrical energy.



10 megawatt - 100 megawatt-hour REDOX SYSTEM  
ELECTRON UTILITY SUBSTATION APPLICATION

**B. Informed Opinion on Photovoltaics**

## INFORMED OPINION OF PHOTOVOLTAICS \*

The present operating efficiencies of the solar cells themselves is approximately 14% to 15%. That is, approximately 14% to 15% of the sunlight which falls on the solar cells is directly converted into electrical energy. The large remainder is used to heat the cell with some of the excess energy taken off by winds in the outside environment. However, when the solar cell is encapsulated with some sort of potting material or behind a glass surface, the overall efficiency of the cell drops to approximately 10%. If one also considers the fact that the solar cells do not cover the entire area of the panel on to which they are mounted, (called a module) the overall efficiency of the module drops to the order of 6% to 7%. Consequently, if photovoltaic modules are mounted on a roof of a building, it may be assumed that approximately 6% to 7% of the solar energy falling over the area of this solar array will be converted into electrical energy. Stated in another way, if we assume that the solar insolation rate is approximately 1kW per square meter, the available electrical energy we may obtain from the photovoltaics would be approximately 60 to 70 watts per square meter.

In the future, the anticipated efficiency of the individual cells is to be raised to a value of about 18%. Improvements will also be made in the mounting of the cells to the module to make better utilization of the space. In some modules designs, it may be anticipated that the overall efficiency of the module may approach approximately the efficiency of the encapsulated cells.

The current cost of a 10Kw buy would be the order of 10 to 15 dollars per watt, depending on the particular organization and timing of the buy. In addition to the cost of the photovoltaic modules, there will be additional cost for mounting of the

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\* Submitted by Dr. Gilbert C. Yanow, Jet Propulsion Labs, Inc.  
Pasadena, CA.

modules to form the array on the roof of the house. This cost might be the order of two to five dollars per watt additional. At the present time, delivery time is also a problem. Current delivery schedules for this size buy are in the range of four to five months. The wisest design procedure would be to incorporate the photovoltaics as part of the roof structure. In this case, the additional cost for supporting the arrays, would probably be absorbed in the cost that would be allocated for the actual roof structure itself.

In addition to the photovoltaic modules themselves, there is a need for other support systems. In the most basic designs, these support systems would be (1) a charge control system, (2) an energy storage system, (3) possibly some sort of power conditioning system that would either allow the operation of the AC equipment or the interfacing into the AC grid network, (4) Possibly some sort of energy management system which would not allow the energy storage system to be drained beyond some crucial point, and (5) possibly some sort of auxiliary input to the storage system to be used in the case of insufficient solar energy. There is also a possibility for some sort of maximum power control system. That is, a method of varying the resistive component of the load which the photovoltaics see to maximize the energy output from the photovoltaic modules themselves.

Photovoltaic installations require the same engineering principles required with any other solar installation; that is proper orientation of the cells, proper tilt of the cells, proper sizing factors, etc. It is the opinion of the author that when dealing with photovoltaics, it should not simply be "business as usual" in relation to using electrical energy. That is, one should not have the same wasteful electrical energy habits that govern our lives today in this future photovoltaically powered home. There should be a program to develop special high efficiency DC electrical appliances. The use of low efficiency AC motors should be minimized. Energy management systems should be instituted into the home to minimize the waste of electrical

energy. The use of DC power will entail a compromise between wire size, current demand, and voltage of the storage system may have to be determined. It is hoped that a voltage low enough to allow additional features of safety might be instituted. A possible compromise might a 24 to 32 volt systems.

The National Photovoltaic program is aiming at having a much better availability and lower cost of equipment by the middle of this current decade. The published aim is to have the cell modules themselves at approximately 70¢ per watt by 1986 with installed costs, i.e., a module installed on the roof, at approximately two to three dollars per watt. This goal may not be obtained. From discussions with the industry, it is anticipated that a real world price at the mid 1980's might be 2 dollars per peak watt modular cost. At the present time there is a shortage of high grade silicon, the basic building material of the photovoltaic cell. Resolution of this problem will have a bearing on the availability of the materials over the next few years. The industry and government are facing squarely up to this dilemma and it is anticipated that availabilities by the middle of the 1980's should at least be no worst and perhaps better than the present time.

As stated, the present availability is at approximately four to five months wait. There is about one half dozen suppliers available to chose from in the Western Region of the United States.

Critical design areas would be how these will be fitted into the current structure of the roof, taking into consideration the design features such as heating and expansion of the modules at a different rate than the rest of the roof structure, possible cleaning mechanisms, sufficiently durable surfaces to allow walking on the roof as it is now done, and protection from vandalism. Some effort should also be devoted to methods of wiring the modules together to allow for maintenance at a larger date and possibly monitoring of the equipment via small computers. The present reliability of modules is still being improved upon. Modules in todays market have designed life

times of approximately ten years. By the latter part of this decade that design figure should be increased to a period of twenty years. On the whole, photovoltaic modules that have a metal backing with a glass facing seemed to stand up well over a long period of time with minimum failures. There also seems to be very little correlation between the way a photovoltaic module may look and the way it may electrically operate. Some modules that look like they are badly damaged still seem to function at a very satisfactory rate. The problems of failure and poor reliability have been primarily evident in modules that are made of plastic or use a plastic type covering. The industry is turning away from this design and these problems should not occur in future products. Another critical feature of photovoltaics systems, especially mounted in the normal roof of the structure, will be the cooling system of the cells. As cells continue to heat, their efficiency falls off. The normal operating cell temperature of photovoltaic systems is usually in the range of 50 to 60°C. As the cell temperature is increased, there are substantial drop-offs in the power output of the photovoltaic module. If the modules are mounted in such a way that the backside of the photovoltaic system is allowed to over heat, efficiency may drop-off. Consequently, designs might be required that will allow a natural air flow above and below the photovoltaic modules while having insulation below this air channel to limit lost or heat input into the home proper.

The servicing and maintenance of the photovoltaics should be minimal. If the systems are perhaps over designed by 15%, there could be long delays between requirements of washing the photovoltaic system. If the average rain fall of the area is good, nature may be able to accomplish this task with a minimum extra input by man. There may be servicing requirements involved with the other support systems of the overall photovoltaic system, as might be expected with any electronic device. After any initial "teething operations" the systems should be relatively maintenance and service free.

There are safety factors associated with Photovoltaics as with any other system. Many of these factors are simply associated with the mechanical way of handling and installation of the photovoltaic modules. If the systems are kept at low voltages the electrical hazards should be minimal, perhaps even less than the normal electrical wiring of a home. There should be care given to minimize any possible short circuiting of wires. Although the voltage may be operating at a low level, there is a possibility of rather high currents, and if these occur under short circuit conditions, electrical fire as with any short circuit might occur. A possible environmental impact on the homes in the area might be the reflection of sunlight from the glass surfaces onto structures surrounding the home, a problem not unique to photovoltaic systems, but common to many solar system. This might require the addition of parapits or other structures that will simply be used as a shade from the reflected light.

If the aim of the ATH is to truly show advance technology in the home market, and the ability and advantages of using alternative energy sources wisely, it is practically unthinkable to build this home without the addition of some photovoltaic system.

Photovoltaics is a child of the space age and is now being "educated" to allow its entry into the normal everyday real world. By the time of the opening of this project, it is quite possible that photovoltaics will be many steps closer to commercialization on the American market. At the present time this is realized in remote applications.

That is, if an application is in an area where the electrical power source must be supplied by the continual replacement of batteries, use of fossil energies, or some other continually maintained source, the application of a photovoltaic system is very cost effective. Such systems are presently finding great utility in areas such as the microwave system across New Guinea and in the Northern parts of Australia. The major disadvantages of photovoltaic systems at this time have been the lack of acceptable storage system that the average home owner could use and the lack of the availability of power conditioning equipment to be used on a large scale photovoltaic grid interconnect scheme. The utilization of redox storage system which the ATH project anticipates, might be a significant step forward in the area of energy storage with photovoltaic

systems. There is great interest at the present time in signal conditioning and inter-connecting with grid systems. Consequently it should be anticipated that this equipment will be available in the not to distant future.

Gilbert Yonow, PhD  
14 March 1980



**C. Preliminary Estimate of PV Array & REDOX Sizes**

**Preliminary Estimate of PV Array  
and REDOX Sizes for the ATDH**

**Contents**

**Executive Summary**

- I. Climate data for Moffett Field**
- II. Assumption and analysis for ATDH Space conditioning loads**
- III. Electrical loads other than space conditioning**
- IV. PV array and storage system**
- V. Insolation data**
- VI. Array sizing calculations and REDOX power rating**

**Submitted by**

**Don Maund**

## Executive Summary

The analysis described in this report was undertaken in order to estimate sizes of the photovoltaic array and storage system needed for an ATDH of nominal 2500 ft<sup>2</sup> living area located at NASA-ARC. Observations and conclusions are as follows:

1. A PV array of 120m<sup>2</sup> (1290 ft<sup>2</sup>) will provide approximately 81% of the normal house energy loads over a one year period.

	<u>Annual load (kwh)</u>
Lights, appliances	6278
Hot Water	3796
Heating	2785
Cooling	<u>287</u>
	13146
Direct usable energy supplied by array	10648 = 81%
Overgeneration (approx.)	290

2. A REDOX unit rated at 5 kw and 40 kwh capacity would supply all average daily loads 97% of the time. For this 97% of the year utility back up power could be drawn during off-peak periods at night. During the remaining 3% of the time it may be necessary to draw line current at day-time grid peak periods unless specific conservation adjustments were made. (Slight shifts in normal times of appliance use, for example.)

REDOX output would be a nominal 140 vdc @ 36 amp max to the inverter. The inverter would be rated to deliver 5 kva at 110/220 volt AC, 60 cycle, line commutated power.

3. No allowances were made for other high energy systems likely to be displayed with the ATDH since such systems have yet to be engineered and insufficient data is at hand. For instance, an incinerating device for dispersing of toilet, food and greywater sludge waste might consume at least 5 kwh per day, a 14% increase in annual house demand. However, since energy consumption for this purpose could be scheduled for non-peak demand periods it would not require increased capacity for the power systems. But it would,

of course, reduce the 80 % on-site energy production objective. There would, of course, be many ameliorating, house related and community benefits to justify increased on-site energy consumption for a sewer-less house.

4. A basic assumption in the analysis is that maximum direct use is made of energy generated by the array. This implies, for example, that any nighttime "topping-up" of the REDOX with line power would be predicated on next day solar output. That is, the REDOX would not be fully charged from the line if that were to cause load shedding (or feedback to the grid) due to a full REDOX during sunlight the next day.

It is feasible to consider a power control system which could accept data from a tie line to Moffett Field NAS control tower. Arrangements could be made for tower personnel to supply appropriate forecast data from the daily aviation weather reports. These data would be used by the decision mechanisms of the control unit to accept only the optimum amount of topping-up power from the grid each night.

A parallel input channel to the power control could also accept householder supplied data on anticipated house activity changes (changing requirements due to houseguests or vacation periods, for example).

The primary value of such a system is that it reduces to a minimum the wasteful transmission, back and forth, between the REDOX and the grid. Estimation of the economic cost/benefit ratio should be made as soon as a suitable computer simulation package is available for detailed analysis.

As far as is known, such a forecast-based power control system has not yet been proposed or demonstrated. If justified for inclusion in the ATDH, it would therefore be a major demonstration of an innovative application of household management computer systems.

5. Clearly, a computer simulation package is needed for detailed study of ATDH systems and related engineering design. Efforts should proceed to acquire or enlist such a capability as soon as possible. Apart from systems evaluation, such a program package will provide a base for devising innovative computer-controlled animated video sequences to display in a compelling way the highly complex dynamics of energy flows within the ATDH.

## I. CLIMATE DATA FOR MOFFETT FIELD LOCATION

It was necessary to construct typical day temperature profiles for the Moffett Field location based on the monthly max/min statistical data shown in Table 1. This was done as follows:

1. Months were lumped into three "seasons";

WINTER = NOV, DEC, JAN, FEB

SUMMER = JUN, JUL, AUG, SEP

SPRING/FALL = MAR, APR, MAY, OCT.

2. Average MAX/MIN temperatures for the season groupings are:

	<u>AVE MAX</u>	<u>AVE MIN</u>
WINTER	59° F	43° F
SUMMER	74° F	55° F
SPR/FALL	67° F	48° F

These temperature ranges are assumed to prevail 80% of the time for each season.

3. Within each season a typical low daily range and high daily range was assumed each of which would prevail 10% of the time.

	<u>LOW RANGE</u>	<u>HIGH RANGE</u>
WINTER	35 - 51	51 - 69
SUMMER	50 - 65	65 - 86
SPR/FALL	41 - 58	48 - 79

In this manner, nine daily temperature ranges were defined consisting of three seasons each containing typical daily low, average and high ranges.

4. A diurnal temperature cycle was defined as shown in Figure 1. This was used to estimate the hourly temperature distribution for each of the nine typical days used to define the annual temperature pattern.

The results are displayed in Table 2. Average temperatures are shown for each period throughout the day. This cuts computational workload and provides some smoothing of the data.

**TABLE 1**  
Climatological Data for Mountain View (Moffett Field AFB)

Latitude: 37°25' Longitude: 122 03' Elevation: 34'													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
<b>TEMPERATURE (°F)</b>													
average monthly	48	52	53	57	59	64	63	65	63	61	55	50	58
average daily $\frac{\text{max}}{\text{min}}$	$\frac{56}{40}$	$\frac{60}{43}$	$\frac{62}{44}$	$\frac{66}{47}$	$\frac{68}{50}$	$\frac{73}{54}$	$\frac{73}{56}$	$\frac{73}{56}$	$\frac{73}{55}$	$\frac{71}{51}$	$\frac{65}{46}$	$\frac{57}{42}$	$\frac{62}{49}$
extreme $\frac{\text{max}}{\text{min}}$	$\frac{76}{21}$	$\frac{75}{26}$	$\frac{83}{30}$	$\frac{87}{32}$	$\frac{98}{38}$	$\frac{104}{43}$	$\frac{93}{45}$	$\frac{96}{47}$	$\frac{96}{41}$	$\frac{92}{33}$	$\frac{87}{29}$	$\frac{76}{27}$	$\frac{104}{21}$
<b>DEGREE DAYS °</b>													
heating (base 65°F)	549	400	378	271	164	74	34	33	37	149	342	518	2969
cooling (base 65°F)	0	0	0	0	9	47	63	58	57	0	0	0	236
<b>WIND</b>													
Mean speed (mph)	6	6	7	7	7	8	7	7	6	6	5	6	6
Max. speed* (mph)	64	64	51	49	44	46	35	36	38	53	53	62	64
Prevailing direction	SE	SE	NNW	NNW	NNW	NNW	NNW	NNW	NNW	NNW	NNW	SE	NNW
<b>FREEZE DAYS PER MONTH</b>	4	1	<0.5	<0.5	0	0	0	0	0	0	1	2	8
<b>PRECIPITATION (in. water)</b>													
average	2.9	1.9	1.9	1.1	0.4	0.1	T	T	0.2	0.6	1.7	2.5	13.3
$\frac{\text{max}}{\text{min}}$	$\frac{2.3}{2.3}$	$\frac{1.5}{1.5}$	$\frac{1.3}{1.3}$	$\frac{1.2}{1.2}$	$\frac{0.7}{0.7}$	$\frac{0.4}{0.4}$	$\frac{0.3}{0.3}$	$\frac{0.2}{0.2}$	$\frac{2.0}{2.0}$	$\frac{2.5}{2.5}$	$\frac{2.8}{2.8}$	$\frac{2.2}{2.2}$	$\frac{2.8}{2.8}$
<b>RELATIVE HUMIDITY (%)</b>													
4 AM	85	85	82	83	83	83	86	86	82	81	84	86	84
1 PM	66	63	58	57	58	58	62	61	55	54	60	67	60

\* Peak gust speed.

\* Data for Palo Alto Jr. Museum 37°24'N 122° 08'W Elevation 25'

Source of climatological data: AWS climatic summary.

**FIGURE 1**  
**DIURNAL TEMPERATURE CYCLE**

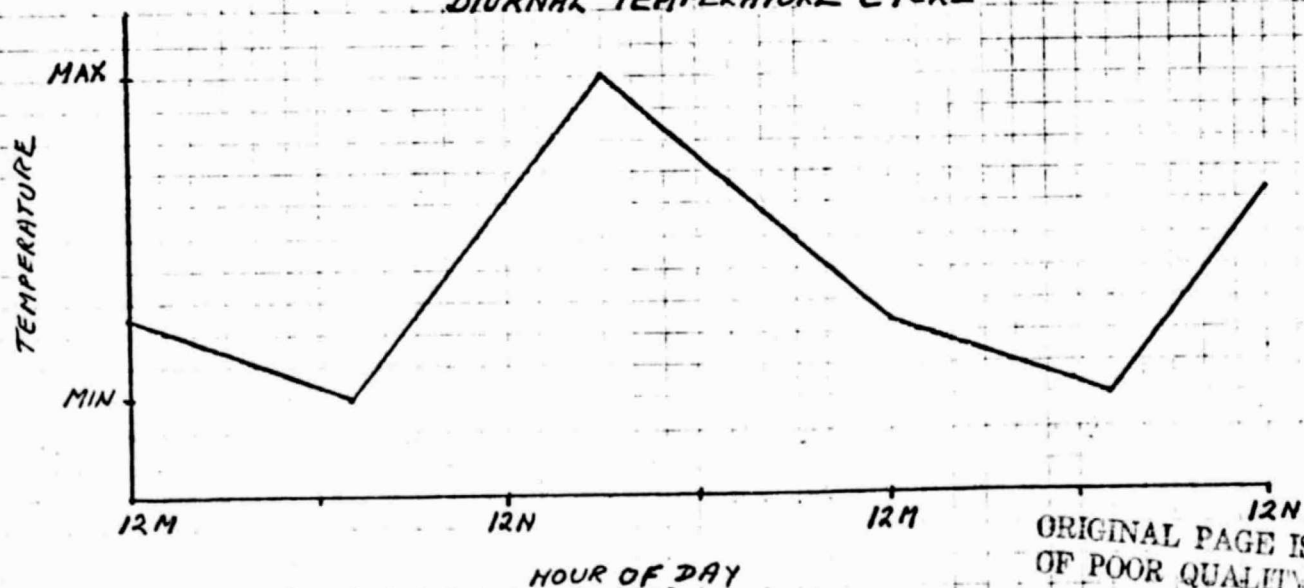


TABLE 2.

ESTIMATED DAILY TEMPERATURE  
PROFILES FOR MCFFETT FIELD

DAILY 2 HOUR PERIODS	NOV.	DEC.	JAN.	FEB	JUN.	JUL.	AUG.	SEP.	MAR.	APR.	MAY:	OCT.
	10% LO	80% AVE	10% HI		10% LO	80% AVE	10% HI		10% LO	80% AVE	10% HI	
6 8	35	43	51		50	55	65		41	48	58	
8 10	39	47	56		54	60	70		45	53	63	
10 12(NOON)	43	51	60		58	65	76		50	58	69	
12 2	47	55	65		61	69	81		54	62	74	
2 4	51	59	69		65	74	86		58	67	79	
4 6	48	56	66		62	71	82		55	64	75	
6 8	46	54	63		60	68	79		52	61	72	
8 10	43	51	60		58	65	76		50	58	69	
10 12(MIDNIGHT)	40	48	57		55	61	72		47	54	65	
12 2	39	47	55		53	59	70		45	52	63	
2 4	37	45	54		52	58	68		44	51	61	
4 6	36	44	52		51	57	67		42	50	60	
MAX °F	51	59	69		65	74	86		58	67	79	
MIN °F	35	43	51		50	55	65		41	48	58	
DAYS IN PERIOD	12	96	12		12	98	12		12	99	12	

## II. ASSUMPTIONS & ANALYSIS FOR ATDH SPACE CONDITIONING LOADS

### A. HOUSE MODEL FOR 'ATDH' AT MOFFETT FIELD:

ASSUME A NOMINAL RECTANGULAR LIVING SPACE  $70\text{ FT} \times 35\text{ FT} = 2450\text{ FT}^2$

SOUTH FACING WINDOW AREA =  $68\text{ FT}^2$

NON-SOUTH ORIENTED WINDOWS =  $\underline{159}$

TOTAL WINDOW AREA =  $227$

TOTAL AREA OF DOORS =  $84$

SOLID WALL SURFACE =  $\underline{1579}$

TOTAL EXTERIOR WALL SURFACE =  $1890\text{ FT}^2$

### B. CONDUCTANCE VALUES:

PARAMETRIC VALUES USED IN THIS ANALYSIS WERE DERIVED FROM DATA CONTAINED IN ASHRAE HANDBOOKS, THE MINIMUM ENERGY DWELLING WORKBOOK, & NUMEROUS OTHER REPORTS OF ADVANCED CONCEPT RESIDENCE STUDIES.

1. SOLID WALLS ARE R19 STANDARD WITH  $2 \times 6$  STUDS AT  $24"$  SPACING.

$$U_s = .063\text{ BTU/HR.}^\circ\text{F. FT}^2$$

2. WINDOWS ARE 2 GLAZED WITH INTERNAL SHADES.

$$U_w = .680$$

3. DOORS ARE STEEL FACED FOAM CORE.

$$U_d = .106$$

4. CEILINGS ARE R30 STANDARD

$$U_c = .045$$

5. FLOORS. ASSUME FULLY INSULATED CONCRETE SLAB - NO BASEMENT.  
& 1 INCH CONDUCTANCE CONTRIBUTION

### C. OVERALL ENERGY CONDUCTION RATE FOR BUILDING

$$\begin{aligned} Q_G &= (.063)(1579) + (.068)(227) + (.106)(84) + (.045)(2450) \\ &= 373.1\text{ BTU/HR.}^\circ\text{F} \end{aligned}$$



#### D. VENTILATION HEAT LOSSES

ASSUME DEMAND CONTROLLED VENTILATION @ AVE RATE OF 0.5 AIR CHANGES/HR

$$\text{VOLUME} = 2450 \times 8 \times 0.5 = 9800 \text{ FT}^3/\text{HR}$$

$$\text{AIR DENSITY} \approx .075 \text{ LB/FT}^3$$

$$\text{HEAT CONTENT} \approx .240 \text{ BTU/LB.}^\circ\text{F}$$

$$\therefore \text{POTENTIAL HEAT LOSS} = 9800 \times .075 \times .240 = 176.4 \text{ BTU/HR.}^\circ\text{F}$$

ASSUME 30% HEAT EXCHANGE RECOVERY

$$\therefore \text{EFFECTIVE HEAT LOSS} = Q_v = .70 \times 176.4 = 123.5 \text{ BTU/HR.}^\circ\text{F}$$

#### E. INTERNAL ENERGY CONTRIBUTIONS

	(BTU/HR)	
	SUMMER	WINTER
PEOPLE	800	800
LIGHTS & APPLIANCES	900 *	2100 *
TOTAL	1700	2900

\* PRINCIPLE DIFFERENCE DUE TO VENTING CONDENSER COILS OF REFRIGERATORS, ETC. TO INTERIOR SPACE IN WINTER FOR NET HEAT GAIN & TO EXTERIOR IN SUMMER TO REDUCE A/C LOAD.

#### F. DESIGN LOADS FOR HEAT PUMP

1. HEATING : INTERIOR TEMP.  $65^\circ\text{F}$   
EXTERIOR TEMP  $35^\circ\text{F}$  = ASHRAE 99% CONDITION FOR SAN FRANCISCO AIRPORT.

$$\text{MAX. CONDUCTION LOSS} = 373.1(65-35) = 11,193 \text{ BTU/HR}$$

$$\text{MAX VENTILATION LOSS} = 123.5(65-35) = 3,705$$

$$\text{LESS: INTERNAL CONTRIB.} = \underline{-2,900}$$

$$\text{MAX HEAT LOAD} = 11,998 \text{ BTU/HR}$$

F. (CONTINUED)

2. COOLING: INTERIOR @ 75°F DB, 50% REL. HUM (62°F WB)

EXTERIOR @ 83°F DB, 80% REL. HUM. (78°F WB)

= ASHRAE 99% CONDITION FOR SAN FRANCISCO AIRPORT

(a) CONDUCTION LOAD =  $373.1(83-75) = 2,985 \text{ BTU/HR}$

(b) INTERNAL LOAD =  $1700 \text{ BTU/HR}$

(c) INFILTRATION (VENT.):

ENTHALPY OUTER =  $41 \text{ BTU/LB}$

ENTHALPY INNER =  $28 \text{ BTU/LB}$

AIR MASS =  $9800(.075) = 735 \text{ LB/HR}$

HEAT LOAD =  $735(41-28) = 9,555 \text{ BTU/HR}$

(d) WINDOWS:

SOUTH FACING AREA =  $68 \text{ FT}^2$

TRANSMITTANCE  $\approx .80$

INSULATION (NORMAL TO WINDOW) =  $80 \text{ BTU/FT}^2 \cdot \text{HR}$

HEAT LOAD =  $68 \times 80 \times 0.80 = 4,352 \text{ BTU/HR}$

DESIGN MAX COOLING LOAD =  $(a) + (b) + (c) + (d)$

=  $2985 + 1700 + 9555 + 4352$

=  $18,592 \text{ BTU/HR.}$

SUMMARY DESIGN MAX LOADS

HEATING	= $11,998 \text{ BTU/HR}$
COOLING	= $18,592 \text{ BTU/HR}$

## G. HEAT PUMP SELECTION

THE SMALLEST UNIT FOR WHICH DATA WAS CONVENIENTLY AVAILABLE  
WAS THE GE WEATHERTRON # BWC024B RATED AT 25,500 BTU/HR  
FOR COOLING & 25,000 BTU/HR HEATING.

PERFORMANCE DATA GIVEN BELOW:

### PERFORMANCE DATA COOLING

(ALL CAPACITIES ARE NET WITH INDOOR FAN HEAT ALREADY DEDUCTED)

#### BWC024B AT 800 CFM

O.D. D.B.	I.D. W.B.	TOTAL CAP.	SENS. 72	CAP. 74	AT ENTERING 76	D.B. TEMP. 78	COMP. 80	APP. DEW PT. (1)
85	59 63 67 71	23.9 25.2 26.4 27.7	19.7 16.0 12.7 9.7	21.2 17.5 14.0 10.9	22.8 18.9 15.4 12.2	24.0 20.4 16.7 13.5	24.3 21.8 18.1 14.7	2.6 2.7 2.7 2.8
90	59 63 67 71	23.3 24.7 26.0 27.4	19.5 15.9 12.6 9.6	21.1 17.3 13.9 10.8	22.6 18.8 15.3 12.1	23.5 20.3 16.7 13.4	23.9 21.7 18.1 14.7	2.7 2.8 2.9 2.9
95	59 63 67 71	22.6 24.1 25.5 26.9	19.2 15.7 12.4 9.4	20.8 17.1 13.8 10.7	22.4 18.6 15.2 12.0	23.0 20.1 16.4 13.3	23.4 21.6 17.9 14.6	2.8 2.9 3.0 3.1
100	59 63 67 71	21.8 23.4 24.9 26.4	18.9 15.4 12.2 9.1	20.5 16.9 13.6 10.5	21.9 18.4 15.0 11.8	22.4 19.9 16.4 13.1	22.8 21.4 17.8 14.4	2.9 3.0 3.1 3.2
105	59 63 67 71	21.0 22.6 24.1 25.7	18.5 15.1 11.9 8.9	20.1 16.6 13.3 10.2	21.2 18.1 14.7 11.6	21.7 19.6 16.1 12.9	22.1 21.1 17.6 14.3	3.0 3.1 3.2 3.3
115	59 63 67	19.0 20.7 22.4	17.6 14.4 11.3	19.1 15.9 12.7	19.6 17.4 14.1	20.1 18.9 15.6	20.6 20.5 17.0	3.2 3.3 3.5

**CORRECTION FACTORS—OTHER AIRFLOWS**  
(multiply or add as indicated)

AIRFLOW	700	800	900
TOTAL CAP.	x0.975	x1.000	x1.025
SENS. CAP.	x0.95	x1.00	x1.05
COMPR. KW	x0.99	x1.00	x1.01
A.D.P.	-1.0	+0.0	+1.0

**VALUES AT ARI RATING CONDITIONS**

TOTAL NET CAPACITY = 25500 BTUH  
AIRFLOW = 800 CFM  
APP. DEW PT. = 53.8 DEG. F  
COMPRESSOR POWER = 2970 WATTS  
I.D. FAN POWER = 215 WATTS  
O.D. FAN POWER = 415 WATTS  
ENERGY EFF. RATIO = 7.1 BTUH/WATT

\*Dry coil condition (Tot. Cap. = Sens. Cap.)  
(1) Comp. KW & App. Dew Pt. valid wet coil only

### PERFORMANCE DATA HEATING

#### BWC024B AT 800 CFM

O.D. TEMP.	HEATING CAP. (BTUH/1000) AT IND. INDOOR D.B. TEMP.				TOTAL POWER IN K.W. AT IND. INDOOR D.B. TEMP.			
	60	70	75	80	60	70	75	80
-18	7.6	6.9	6.5	6.2	1.9	2.0	2.1	2.1
-13	8.3	7.6	7.2	6.8	2.0	2.1	2.2	2.2
-8	9.1	8.4	8.0	7.6	2.1	2.2	2.3	2.3
-3	10.2	9.3	8.9	8.5	2.2	2.3	2.4	2.4
2	11.4	10.5	10.0	9.6	2.3	2.4	2.5	2.5
7	12.7	11.7	11.2	10.7	2.4	2.6	2.6	2.7
12	14.1	13.0	12.5	12.0	2.6	2.7	2.7	2.8
17	15.6	14.5	14.0	13.4	2.7	2.8	2.9	2.9
22	17.3	16.2	15.6	15.0	2.8	2.9	3.0	3.0
27	19.1	17.9	17.3	16.7	2.9	3.0	3.1	3.1
32	21.0	19.7	19.1	18.5	3.0	3.1	3.2	3.3
37	22.9	21.6	20.9	20.3	3.0	3.2	3.3	3.4
42	24.7	23.4	22.7	22.0	3.1	3.3	3.4	3.5
47	26.4	25.0	24.3	23.6	3.2	3.4	3.5	3.6
52	27.9	26.5	25.8	25.1	3.4	3.5	3.6	3.7
57	29.1	27.8	27.1	26.4	3.5	3.7	3.8	3.9
62	29.8	28.5	27.9	27.2	3.6	3.8	3.9	4.0
67	30.0	28.9	28.3	27.7	3.7	3.9	4.0	4.1
72	30.1	29.0	28.5	27.9	3.8	4.0	4.1	4.2

**CORRECTION FACTORS—OTHER AIRFLOWS**  
(Value at 800 CFM Times Corr. Factor =  
Value at New Airflow)

AIRFLOW	700	800	900
HEATING CAP.	x0.980	x1.000	x1.020
COMPR. KW	x1.025	x1.000	x0.975

**VALUES AT ARI RATING CONDITIONS OF:**  
47/43-70 (High Temp. Point)  
17/15-70 (Low Temp. Point)

AIRFLOW = 800 CFM  
HEATING CAP. (High Temp.) = 25000 BTUH  
HEATING CAP. (Low Temp.) = 14500 BTUH  
COMPR. POWER (High Temp.) = 2770 WATTS  
COMPR. POWER (Low Temp.) = 2170 WATTS  
COEFF. OF PERF. (High Temp.) = 2.2  
COEFF. OF PERF. (Low Temp.) = 1.5  
OUTDOOR FAN POWER = 415 WATTS  
INDOOR FAN POWER = 215 WATTS

#### H. ENERGY DEMAND FOR SPACE CONDITIONING.

DESIGN FOR INDOOR TEMP MINIMUM OF 65°F DURING HEATING SEASON

MAXIMUM OF 75°F DURING COOLING SEASON

THE ANNUAL TEMPERATURE RANGE IS DIVIDED INTO 5° BANDS.

FOR EACH TEMPERATURE BAND CALCULATE AN "ENERGY FACTOR" WHICH GIVES THE AMOUNT OF ENERGY CONSUMED BY THE HEAT PUMP FOR EACH HOUR DURING WHICH WEATHER IS WITHIN THE BAND.

#### EXAMPLE FOR 45-49°F BAND:

$$(a) \text{ AVE ENERGY DEMAND (DELIVERED)} = \text{CONDUCTIVE LOSSES} \\ + \text{VENTILATION LOSSES} \\ - \text{INTERNAL HEAT GENERATION}$$

$$= (Q_B + Q_V)(\Delta T) - \text{WINTER GAINS}$$

$$= (373.1 + 123.5)(65 - 47) - 2900 = 6039 \text{ BTU/HR}$$

$$(b) \text{ EFFECTIVE HEAT PUMP CAPACITY WITHIN BAND} = 25700 \text{ BTU/HR}$$

$$(c) \text{ ESTIMATED TIME HEAT PUMP OPERATING FOR EACH HOUR WEATHER} \\ \text{IS WITHIN BAND}$$

$$= \frac{6039}{25,700} = 0.235 \text{ HRS}$$

$$(d) \text{ POWER RATING OF HEAT PUMP WITHIN BAND} = 3.3 \text{ kW}$$

$$(e) \text{ ENERGY CONSUMED FOR EACH HOUR WEATHER IS WITHIN BAND}$$

$$= 0.235 \times 3.3 = 0.776 \text{ kWh.}$$

THEREFORE, KNOWING THE NUMBER OF HOURS FOR WHICH WEATHER IS IN EACH TEMPERATURE BAND, & THE ENERGY FACTOR FOR EACH BAND, THE TOTAL ENERGY CONSUMPTION CAN BE CALCULATED.

TEMPERATURE BAND (°F)	ENERGY FACTOR (kwh/HR)
85+	2.01
80-84	1.92
75-79	1.22
70-74	-
65-69	-
60-64	-
55-59	0.135
50-54	0.458
45-49	0.776
40-44	1.130
35-39	1.520

### III. ELECTRICAL LOADS OTHER THAN SPACE CONDITIONING.

DAILY PROFILES FOR LIGHTS, APPLIANCES & SERVICE  
HOT WATER ARE SHOWN IN FIGURE 2.

FOR PURPOSES OF THIS STUDY IT IS ASSUMED THAT  
THE DAILY USAGE PATTERNS ARE CONSTANT THROUGHOUT  
THE YEAR.

# H. (CONTINUED)

THE ENERGY FACTORS FOR EACH TEMPERATURE BAND, CALCULATED ABOVE, ARE COMBINED WITH DATA IN TABLE 2 (SECTION I) TO DERIVE THE ANNUAL PROFILE OF ENERGY REQUIRED FOR SPACE CONDITIONING SHOWN BELOW IN TABLE 3.

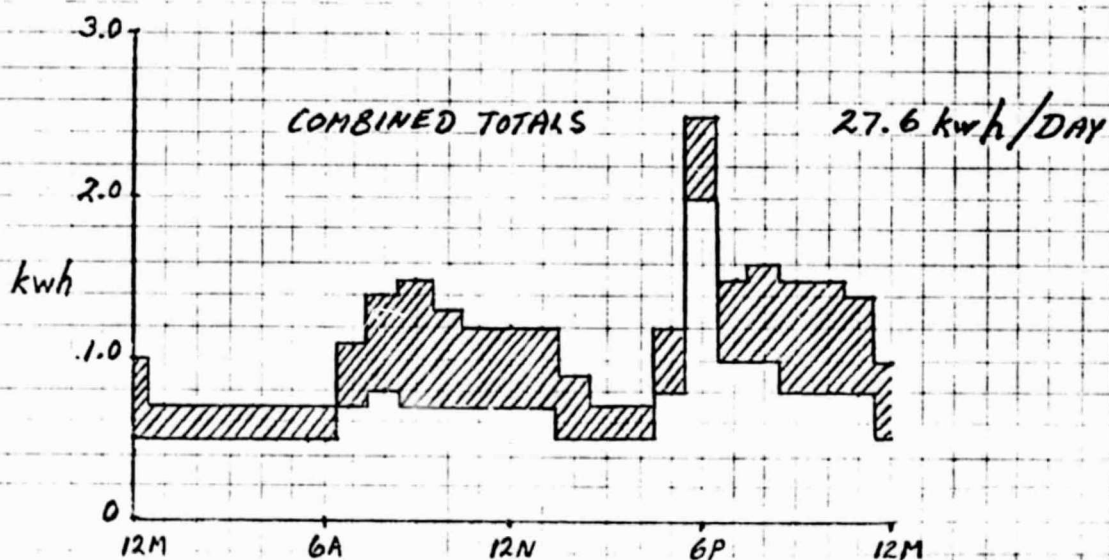
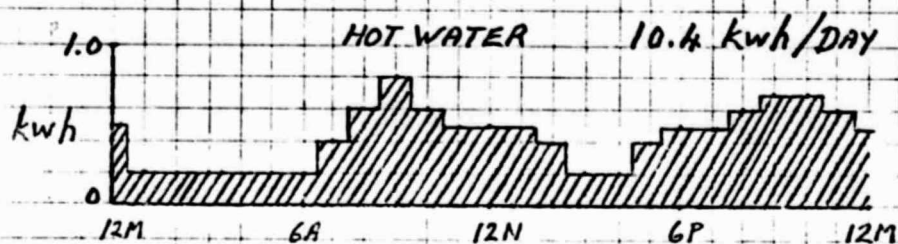
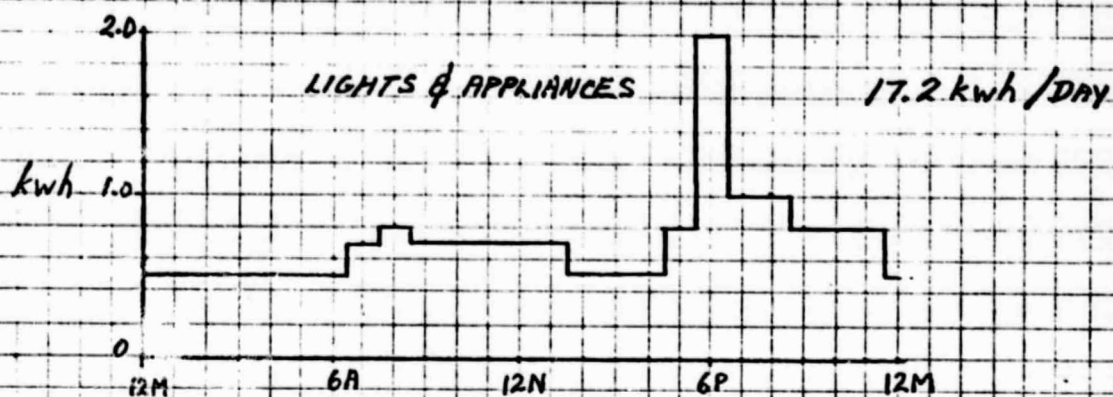
## TABLE 3.

ENERGY FACTORS (KWH/HR) FOR EACH 2 HR PERIOD

DAILY 2 HOUR PERIODS	WINTER			SUMMER			SPRING/FALL					
	NOV.	DEC.	JAN.	FEB.	JUN.	JUL.	AUG.	SEP.	MAR.	APR.	MAY.	OCT.
	12 DAYS LOW	96 DAYS AVE	12 DAYS HIGH	12 DAYS LOW	98 DAYS AVE	12 DAYS HIGH	12 DAYS LOW	99 DAYS AVE	12 DAYS HIGH			
1 12M-2	1.53	0.776	0.135	0.458	0.135	-	0.776	0.458	-			
2-4	1.53	0.776	0.458	0.458	0.135	-	1.13	0.458	-			
AM 4-6	1.53	1.13	0.458	0.458	0.135	-	1.13	0.458	-			
6-8	1.53	1.13	0.458	0.458	0.135	-	1.13	0.776	0.135			
8-10	1.53	0.776	0.458	0.458	-	-	0.776	0.458	-			
10-12N	1.13	0.458	0.135	0.135	-	1.22	0.458	0.135	-			
12N-2	0.776	0.135	-	-	-	1.92	0.458	-	-			
2-4	0.458	0.135	-	-	-	2.01	0.135	-	1.22			
PM 4-6	0.776	0.135	-	-	-	1.92	0.135	-	1.22			
6-8	0.776	0.458	-	-	-	1.22	0.458	-	-			
8-10	1.13	0.458	0.135	0.135	-	1.22	0.458	0.135	-			
10-12M	1.13	0.776	0.135	0.135	-	-	0.776	0.458	-			
AVE ENERGY USE PER DAY (KWH)	27.7	14.3	4.7	5.4	1.08	19.0	15.6	6.7	5.2			
AVE ENERGY USE PER PERIOD (KWH)	332	1373	56	65	106	228	187	663	62			
AVE ENERGY USE PER SEASON (KWH)	1761			399			912					
TOTAL ENERGY USE PER YEAR (KWH)	ORIGINAL PAGE IS OF POOR QUALITY			3072								



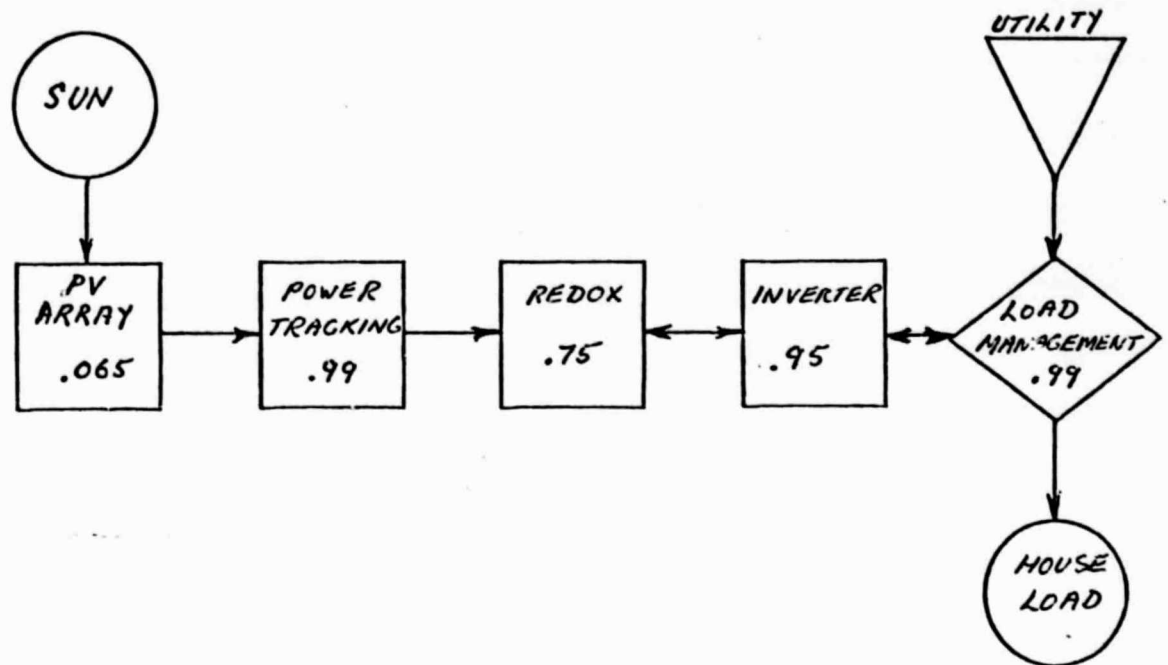
FIGURE 2.  
DAILY PROFILES FOR LIGHTS, APPLIANCES  
& HOT WATER LOADS



ORIGINAL PAGE IS  
OF POOR QUALITY

#### IV. PV ARRAY & STORAGE SYSTEM

BASIC SYSTEM COMPONENTS AND ASSUMED CONVERSION EFFICIENCIES ARE ILLUSTRATED BELOW:



OVERALL SYSTEM CONVERSION EFFICIENCY :

$$= .065 \times .99 \times .75 \times .95 \times .99$$

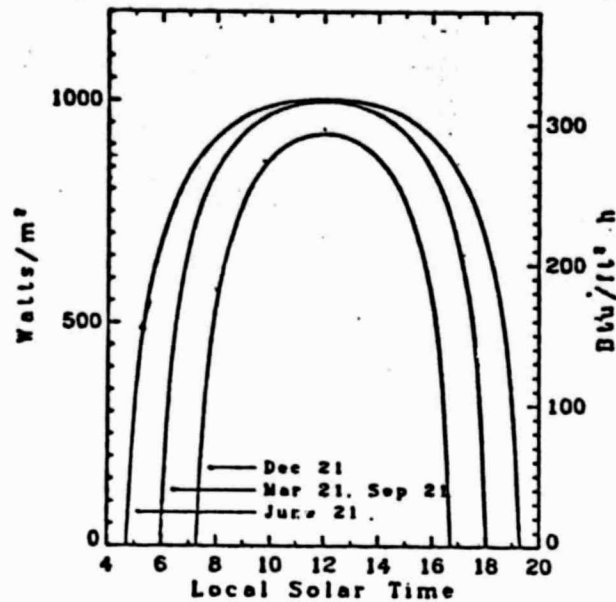
$$= .0454$$



## V. INSOLATION DATA

DAILY DISTRIBUTION OF SOLAR ENERGY & TOTAL MONTHLY RADIATION IS SHOWN BELOW. MONTHLY TOTALS INCLUDE ALLOWANCES FOR CLOUDY DAYS.

Direct Beam (Normal Incidence)  
Redwood City



Total Radiation on a Tilted Surface (Calculated Values)  
Metric Units (kWh/m²)  
Redwood City

Redwood City

SURFACE ORIENTATION	ANGLE OF TILT (DEGREES FROM HORIZONTAL)	DIRECT BEAM + DIFFUSE (GROUND REFLECTION EXCLUDED)												
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTH	15	95	113	164	207	231	230	236	214	187	144	100	82	2002
SOUTH	30	111	126	173	205	218	212	219	207	192	157	115	97	2031
SOUTH	45	120	132	171	191	192	182	190	188	185	161	123	106	1942
SOUTH	60	123	129	160	165	156	143	152	158	168	155	124	109	1742
SOUTH	75	117	119	138	131	113	99	106	120	140	140	117	105	1445
SOUTH	90	105	102	109	89	66	53	59	77	105	116	103	95	1079
SE, SW	15	88	107	158	203	230	230	236	211	181	137	93	76	1949
SE, SW	30	98	114	162	199	218	215	222	204	182	144	102	85	1946
SE, SW	45	102	115	157	186	197	191	198	188	174	143	105	89	1847
SE, SW	60	100	110	145	165	168	160	167	163	158	135	102	89	1662
SE, SW	75	93	99	125	136	134	124	131	133	134	119	93	83	1403
SE, SW	90	80	82	100	103	97	87	93	99	105	98	80	72	1096
E, W	15	72	92	143	192	229	230	233	203	166	120	77	62	1815
E, W	30	69	88	136	181	211	215	218	191	157	114	74	59	1713
E, W	45	65	82	125	165	191	194	197	173	144	106	69	56	1565
E, W	60	58	73	111	145	166	168	171	152	127	94	62	50	1378
E, W	75	51	63	94	121	138	139	142	127	108	81	54	47	1159
E, W	90	41	51	75	96	108	108	110	100	86	65	44	35	921

# VI. ARRAY SIZING CALCULATIONS AND REDOX POWER RATING

SEASON	WINTER	SUMMER	SPRING/FALL
DAYS	120	122	123
HOUSE DEMAND: (kwh)			
SPACE CONDITIONING (TABLE 2, SECTION II.)	1761	399	912
LIGHTS, APPLIANCES, HOT WATER (SECTION III.) (kwh)	3312	3367	3395
TOTAL HOUSE DEMAND: (kwh)	5073	3766	4307
FOR ARRAY AT 45° TILT SOUTH FACING:			
TOTAL RADIATION AVAIL. (kwh/m <sup>2</sup> )	481	745	715
SYSTEM EFFICIENCY (SECTION IV)	.0454	.0454	.0454
NET DELIVERED ENERGY (kwh/m <sup>2</sup> )	21.8	33.8	32.5
AN ARRAY SIZED 120 M <sup>2</sup> WILL DELIVER TO HOUSE LOAD (kwh)	2616	4056	3900
% OF HOUSE DEMAND	52%	100%	91%
ANNUAL AVERAGE % SUPPLIED BY PV SYSTEM	81%		

---

SUMMARY: AN ARRAY SIZE 120 M<sup>2</sup> (1290 FT<sup>2</sup>) ORIENTED SOUTH  
AT A TILT OF 45° FROM HORIZONTAL WILL DELIVER  
81% OF HOUSE LOAD REQUIREMENTS.

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(VI. CONTINUED)

THE FOLLOWING CHARTS SHOW HOUSE LOADS AND PV ENERGY INPUT FOR EACH OF THE NINE TYPICAL DAYS USED IN THIS ANALYSIS. THEY DEMONSTRATE THAT A 5KW MAX POWER SYSTEM IS QUITE ADEQUATE & ALLOWS FOR OCCASSIONAL HIGH PEAK SITUATIONS. AT NO TIME DO TOTAL AVERAGE LOADS EXCEED 4 KW.

NOTES:

- (a) THE LOWER (UNSHADED) BAR CURVE IS THE LIGHTS, APPLIANCES AND HOT WATER LOAD, AND IS ASSUMED TO BE CONSTANT THROUGHOUT THE YEAR.
- (b) THE SHADED PORTION IS THE SPACE CONDITIONING LOAD.
- (c) THE BELL SHAPED CURVE IS THE ESTIMATE AVERAGE PV ENERGY (INCLUDING ALLOWANCES FOR CLOUDY DAYS) DELIVERED BY A 120 M<sup>2</sup> ARRAY, AT 45° TILT, FACING SOUTH.
- (d) THE ANALYSIS IS CONSERVATIVE IN THAT HEAT GAIN VIA RADIATION TRANSMISSION THROUGH WINDOWS IS IGNORED IN NON-COOLING MONTHS BUT ALLOWANCES FOR WINDOW GAINS ARE INCLUDED FOR COOLING MONTHS. THIS ALLOWS A CERTAIN ENERGY CREDIT FOR SERVICE EQUIPMENT SUCH AS FANS, SERVOS, ETC ASSOCIATED WITH SPACE CONDITIONING SYSTEMS.

# WINTER - LOW RANGE TEMPERATURES 12 DAYS / YEAR

ORIGINAL PAGE IS  
OF POOR QUALITY

AV ENERGY INPUT

SPACE CONDITIONING

LOAD

LIGHTS, APPLIANCES

HOT WATER

kWh

4.0

3.0

2.0

1.0

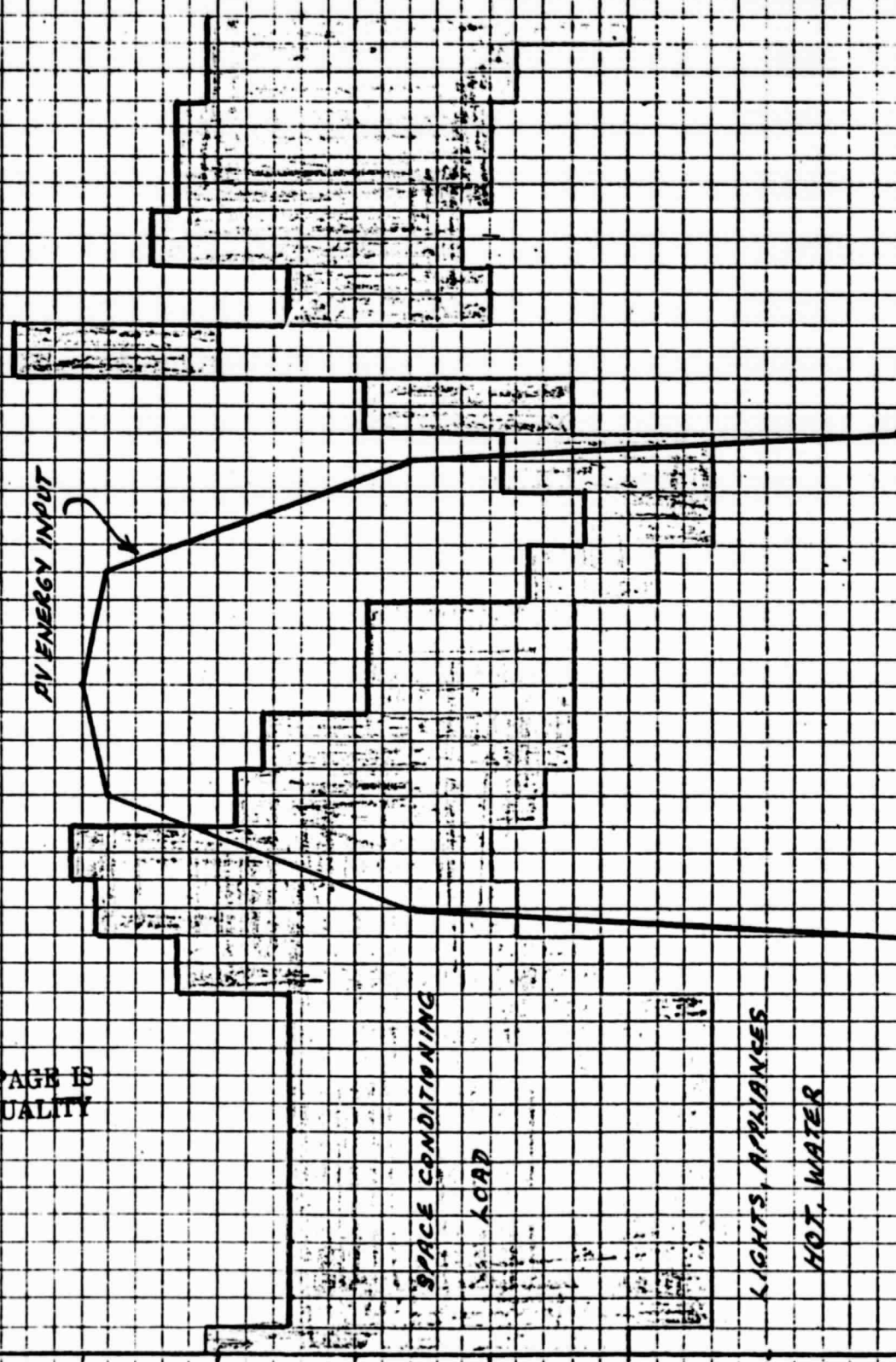
4.0

3.0

2.0

1.0

12M 1 2 3 4 5 6A 7 8 9 10 11 12M



# WINTER - AVERAGE RANGE TEMPERATURES 96 DAYS/YEAR

4.0

3.0

2.0

1.0

PV ENERGY INPUT

SPACE CONDITIONING  
LOADS

LIGHTS, APPLIANCES  
HOT WATER

4.0

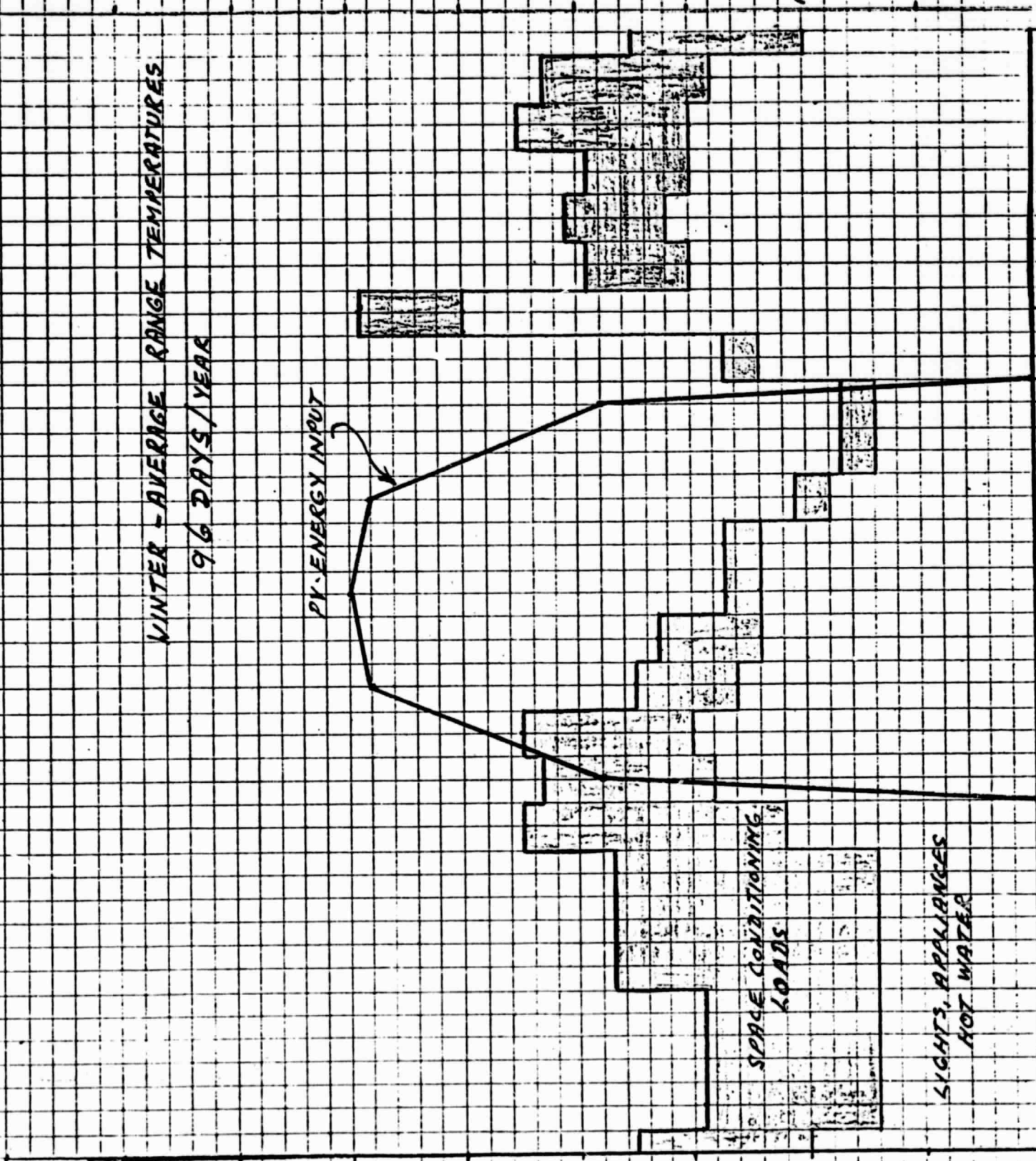
3.0

2.0

1.0

kwh

12M 1 2 3 4 5 6 7 8 9 10 11 12M





# WINTER - HIGH RANGE TEMPERATURES 12 DAYS / YEAR

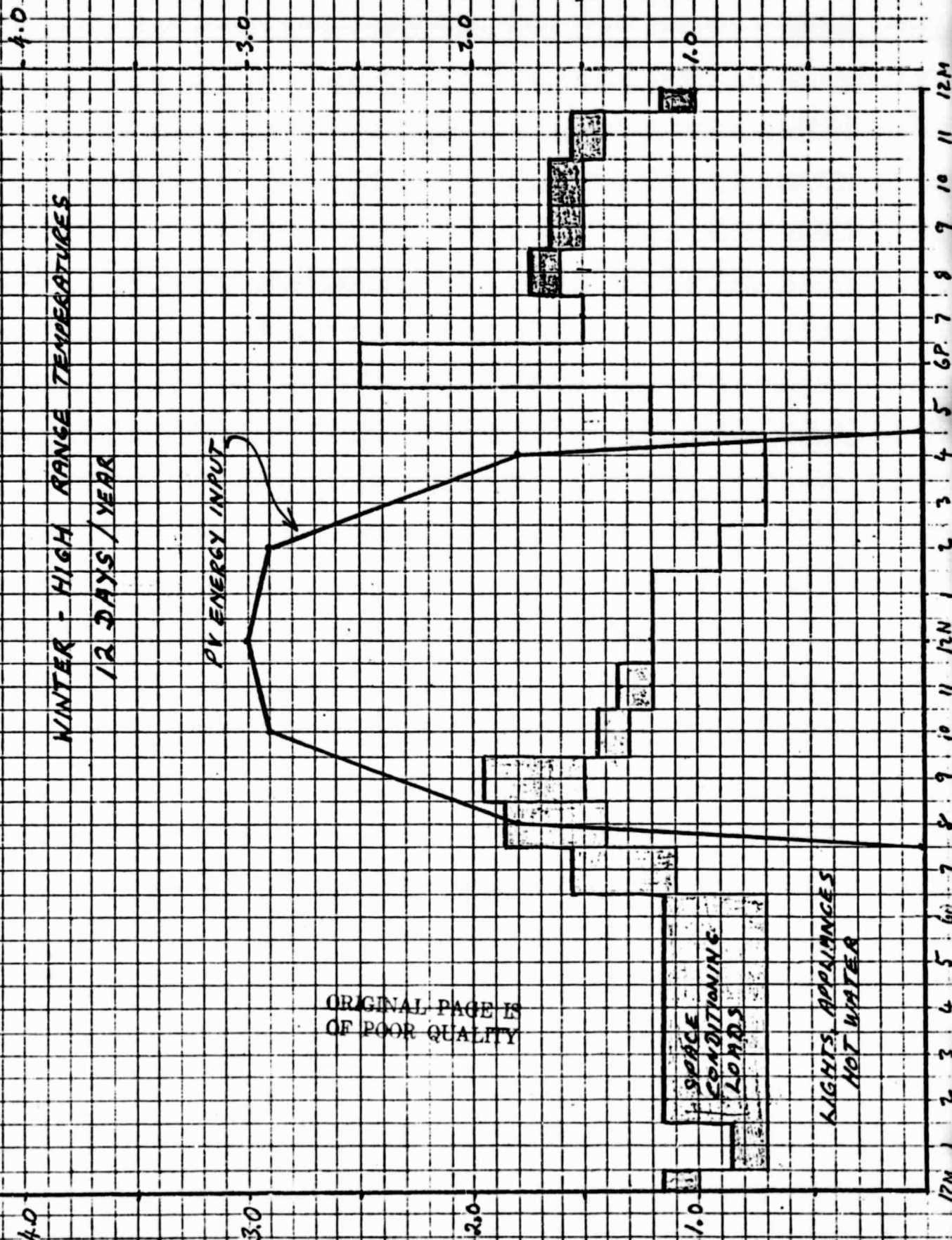
PV ENERGY INPUT

ORIGINAL PAGE IS  
OF POOR QUALITY

SPACE  
CONDITIONING  
LOADS

LIGHTS, APPLIANCES  
HOT WATER

kwh



# SUMMER - LOW RANGE TEMPERATURES 12 DAYS/YEAR

PV ENERGY INPUT

SPACE  
CONDITIONING  
LOADS

LIGHTS  
APPLIANCES  
HOT WATER

4.0

3.0

2.0

1.0

4.0

3.0

2.0

1.0

kWh

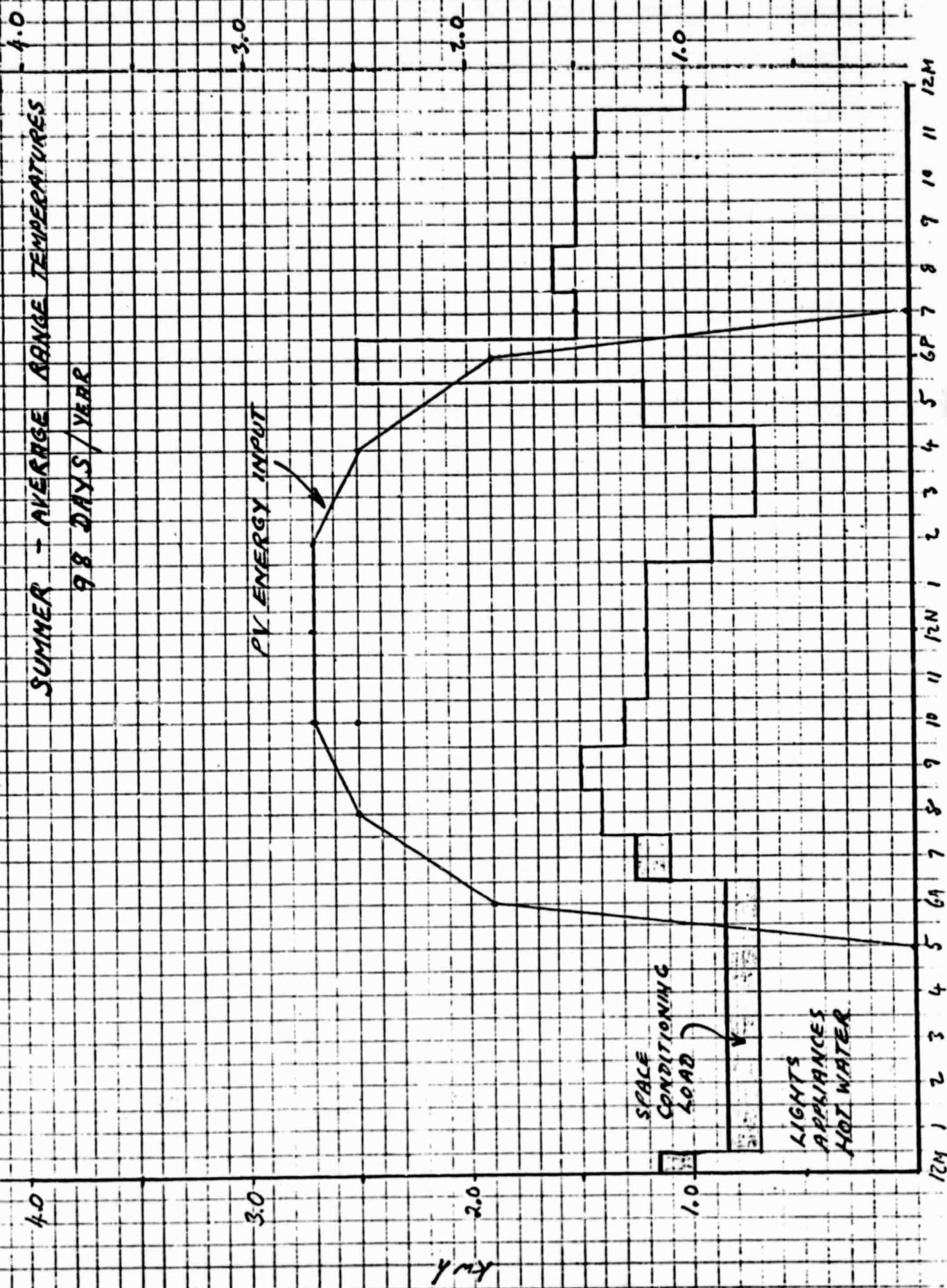
12M 1 2 3 4 5 6A 7 8 9 10 11 12N 1 2 3 4 5 6P 7 8 9 10 11 12M

SUMMER - AVERAGE RANGE TEMPERATURES  
98 DAYS/YEAR

PV ENERGY INPUT

SPACE  
CONDITIONING  
LOAD

LIGHTS  
APPLIANCES  
HOT WATER





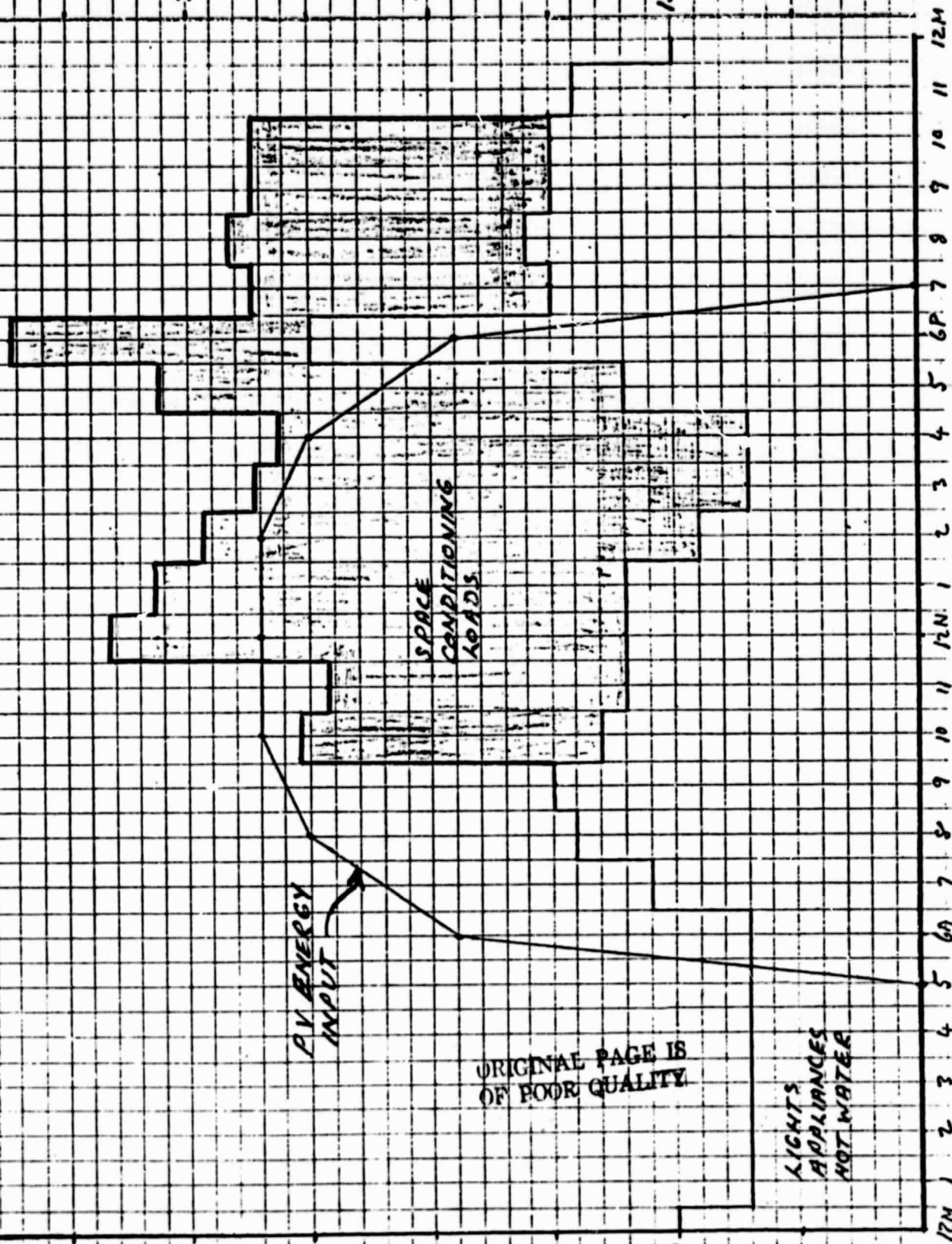
# SUMMER - HIGH RANGE TEMPERATURES 12 DAYS/YEAR

4.0

3.0

2.0

1.0



ORIGINAL PAGE IS  
OF POOR QUALITY

LIGHTS  
APPLIANCES  
HOT WATER

PV ENERGY  
INPUT

SPACE  
CONDITIONING  
LOADS

4.0

3.0

2.0

1.0

kWh

12M

1

2

3

4

5

6A

7

8

9

10

11

12M

1

2

3

4

5

6A

7

8

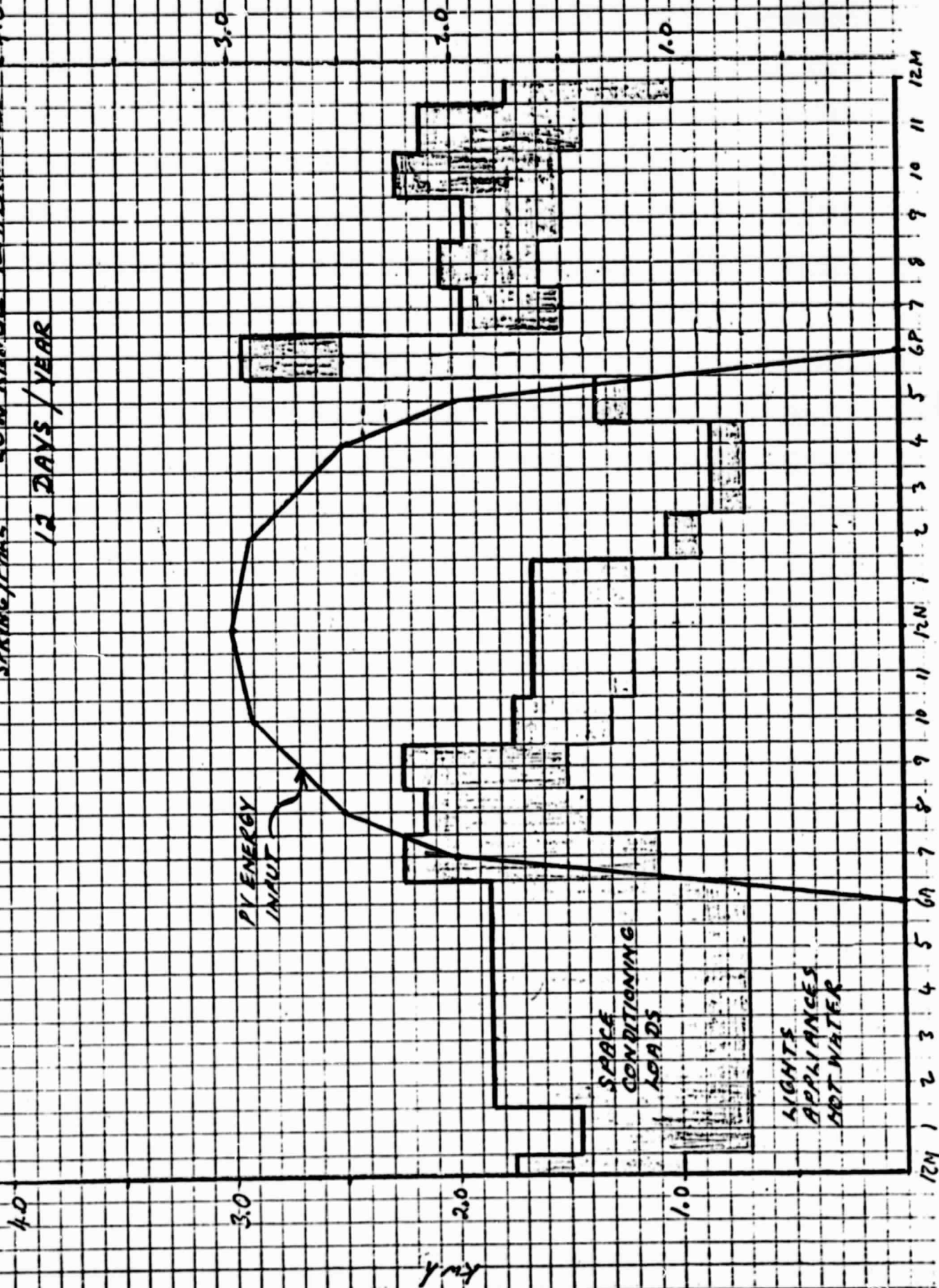
9

10

11

12M

# SPRING/FALL - LOW RANGE TEMPERATURES 12 DAYS/YEAR



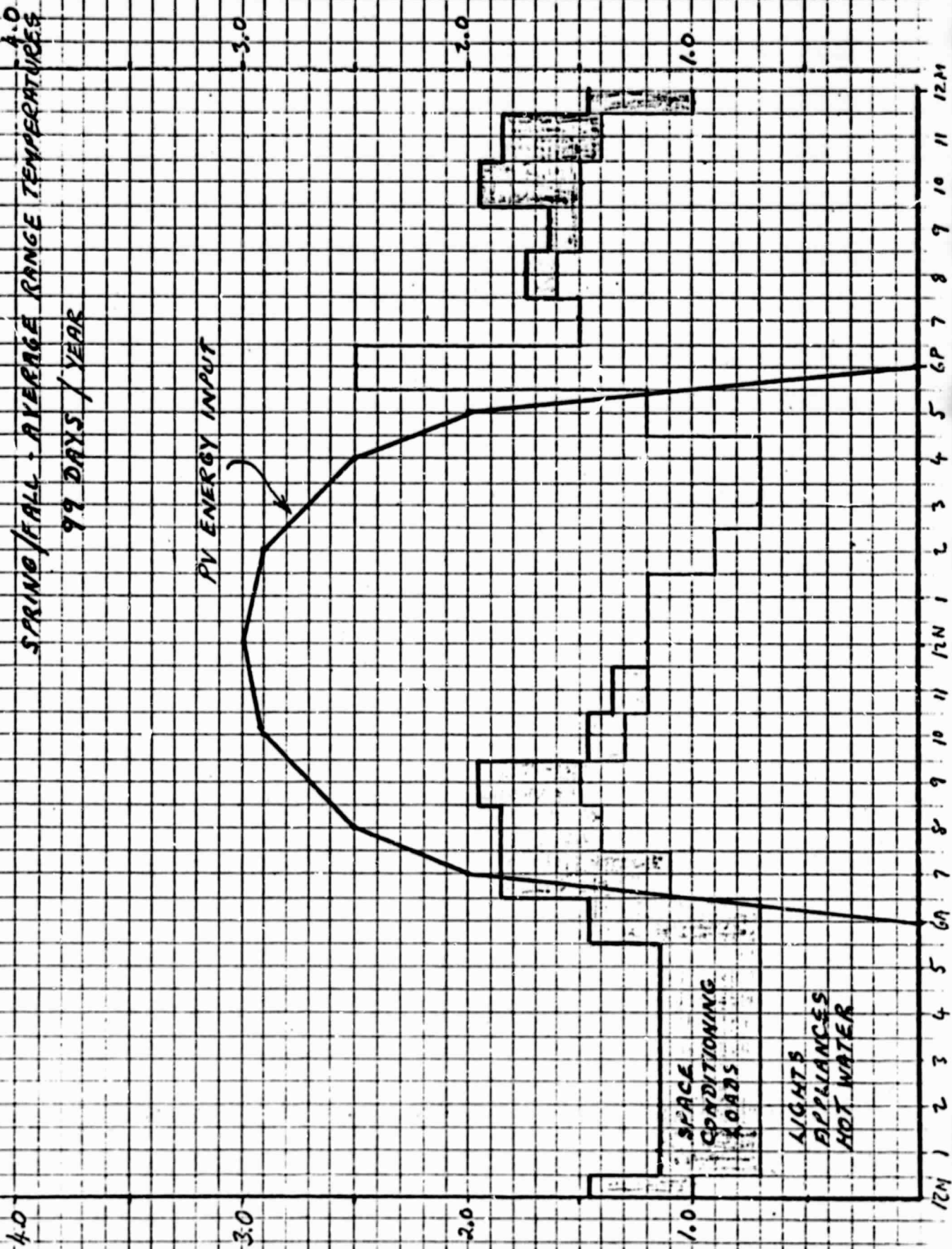
SPRING/FALL - AVERAGE RANGE TEMPERATURES  
99 DAYS / YEAR

PV ENERGY INPUT

SPACE  
CONDITIONING  
LOADS

LIGHTS  
APPLIANCES  
HOT WATER

Yr





SPRING/FALL - HIGH RANGE TEMPERATURES 1.0

12 DAYS/YEAR

PV ENERGY INPUT

SPACE  
CONDITIONING  
LOADS

LIGHTS  
APPLIANCES  
HOT WATER

ORIGINAL PAGE IS  
OF POOR QUALITY

4.0  
3.0  
2.0  
1.0

4.0

3.0

2.0

1.0

3.0

2.0

1.0

12M 1 2 3 4 5 6 7 8 9 10 11 12M

D. On-Site Electric Storage Requirements For the ATDH

June 19, 1980

Mr. Herb Holley  
NASA-Ames Research Center  
M/S 201-8  
Moffett Field, California

Dear Herb:

It is proposed that a REDOX electric storage unit be incorporated into the Advanced Technology Display House (ATDH) to be built at Ames Research Center in 1982. A suitable size unit would deliver 5kw of peak power and have a storage capacity of 40kwh. Ideally, the unit would be engineered to fit into a space of approximately 6X6X8 ft.

It is anticipated that the unit should be available for on-site installation by the January-March, 1982 time frame. A test set-up should be available by September 1981 in order to provide detailed information necessary to integrate the installation with other subsystems in the ATDH. Preliminary data on envelope size, supporting equipment and power requirements, maintenance access needs, system security and all other engineering factors impacting ATDH design and site layout should be available by January 1981.

The enclosed material reviews the reasons supporting the choice of a REDOX unit for inclusion in the ATDH.

Sincerely,



Don Maund  
Technology Coordinator

DM;sk  
Encl.

### ONSITE ELECTRIC STORAGE REQUIREMENTS FOR THE ATDH PROJECT

Photovoltaic (PV) cells are recognized as having great potential for providing clean, high grade electric power generated at the point of use. As such, they are an ideal energy source for residential housing. However, some form of electrical energy storage and/or utility back-up is generally required in PV systems because:

- 1) residential power demand is often out of phase with solar availability.
- 2) random weather conditions can cause interruptions of solar irradiation
- 3) in most applications it is uneconomical to provide solar conversion systems sized to handle occasional peak demands, or even to provide 100% of the aggregate demand.

The extent of the tie-in to the utility grid may range from a high to a relatively low degree of dependence. In systems with a high level of grid dependence, the PV power supply is predominantly feeding energy into the grid system during periods of high insolation and the house draws power from the array or the grid as needed. In this case the PV array is more or less a distributed power source for the grid system. In another sense the grid system may be considered as providing a load-levelling function for the house demand. One of the attractions of this scheme for the homeowner is that a storage system is not needed at the house site. A drawback is that expensive power conversion equipment is required to match the DC power from the PV array precisely to the AC grid power standards.

At the other extreme a PV array is combined with on-site storage which feeds the house power loads directly, via a conversion circuit which doesn't have to be precisely matched to grid power. Extra energy is supplied to the storage from the grid, preferably at night time when grid power demand is low. The benefit of this scheme is that maximum use is made of site generated power with no back and forth transmission switching between the house and grid systems. It also circumvents a host of complex legal and regulating issues regarding utility buy-back and sell back rates.

Most previous analyses have tended to favor the former systems (high grid dependence) because of costs and technical problems associated with conventional battery systems.

More recently, as more information accrues on the potential price and performance factors for advanced technology batteries, the latter type of scheme becomes much more attractive.

A comparison of some candidate advanced technology batteries is given in Table 1. Of the batteries described here the REDOX system, under development at NASA/Lewis Research Center, appears to be most suitable for on-site residential power supplies for the following reasons:

- (a) long life time
- (b) less exposure of house and occupants to hazards
- (c) relative simplicity of system and supporting mechanisms
- (d) very low maintenance requirements
- (e) very forgiving charge/discharge characteristics in matching inputs from PV array and outputs to house load.
- (f) flexible sizing for various capacity requirements

The relatively low energy density currently projected for the REDOX is a small price to pay for the benefits listed above, and is not a major handicap for a stationary, house based application.

The ATDH represents an ideal test bed for a prototype REDOX system in order to study the unit under realistic operating conditions. Of particular interest for residential applications will be the verification of reliability and safety characteristics plus operational efficiency factors. In addition, the prototype system will offer the chance to examine size, controls, product packaging and maintenance considerations relevant to engineering the unit for incorporation into the residential power system.

Preliminary calculations indicate the need for a 5kw/40kwh capacity REDOX for the ATDH project in order to supply 80% of the conventional power loads (space conditioning, lighting, hot water). The actual need may exceed this capacity due to various unconventional loading patterns stemming from other advanced technology systems in the ATDH which have yet to be fully defined. Ideally, the REDOX could be engineered to fit into a 6X6X8 foot utility space.

One of the objectives of the integrated, interactive systems design to be employed in the ATDH is to produce operating data to facilitate analysis of future residential requirements and how best to meet them.



As with other advanced technologies to be featured in the ATDH, it is possible that future REDOX units will be optimally scaled to support small residential clusters rather than individual houses. Nonetheless, the ATDH REDOX demonstration model will be an invaluable source of information for making such determinations.

A study recently released by Sandia National Labs is believed to be the most thorough analysis to date of PV/storage systems. (Parametric Analysis of Residential Grid-Connected Photovoltaic Systems with Storage, D.L. Caskey et al, March 1980). The results indicate that, for economic conditions likely to prevail in the post 1985 era, electric storage will significantly improve PV systems performance in most parts of the U.S. In one comparison, a conventional power supply (no PV or storage) was compared with an optimally sized PV-only system and a comparable PV+storage system. Under the conservative assumptions used in the analysis both PV systems offered equivalently substantial economic savings for the homeowner. In addition, the PV-only system saved the utility the equivalent of 22.6 barrels of oil per year, and the PV+ storage system saved 26.7 barrels, an increase of 18%. More important though, was the finding that while the PV-only system reduced peak hour grid demand by 59%, the PV+ storage system reduced peak grid load by 99.4%. Thus, PV-storage systems provide a load-levelling capability with very valuable economic consequences for the utility in terms of reducing needs for peak load generating capacity.

More detailed studies of the above factors are needed. So far, however, the implication is that REDOX type storage will play an important future role in effecting capital investment as well as fuel economies of strategic importance to the nation.

TABLE 1

TARGET OPERATING CHARACTERISTICS FOR ADVANCED BATTERIES  
(FOR TYPE COMPARISON PURPOSES ONLY)

Item	Units	Unit cell advanced Lead Acid Types	Flowing Electrolyte - Modular		Flowing Electrolyte - System NASA/LEWIS REDOX
			Zinc-Chlorine (Electric Vehicle)	Zinc-Chlorine (Load Leveling)	
In/Out Efficiency	%	60-65	55-60	65-70	65-70
Self Discharge Rate	% per month	5	0	0	0
Energy Density	Wh/lb <sub>3</sub>	23	46	39	25
Energy Density	Wh/in <sup>3</sup>	1.5	2.1	1.7	0.4
Cycle Life	Cycles	500	1000	2500	Not Applicable
Aging Life	years	5-10	10	10	20
Est. Production Cost	\$/Kwh	40-50	40-45*	35-40*	=40
Availability	Year	1984	1985	1985	1985
			*Includes Refrigeration		

TABLE 1 (CONTINUED)

	Unit cell advanced Lead Acid Types	Flowing Electrolyte - Modular (Zinc-Chlorine Electric Vehicle) (Zinc-Chlorine Load Leveling)		Flowing Electrolyte - System NASA/LEWIS REDOX
Operating Advantages:	<ul style="list-style-type: none"> <li>• Evolution from known technology</li> <li>• Small unit modules give sizing flexibility</li> </ul>	<ul style="list-style-type: none"> <li>• Daily deep discharge OK</li> <li>• No permanent damage from full discharge</li> <li>• Terminal voltage steady for low discharge range</li> <li>• Relatively low maintenance</li> <li>• High energy density</li> </ul>		<ul style="list-style-type: none"> <li>• Daily deep discharge OK</li> <li>• No permanent damage from full discharge</li> <li>• Easy measure of charge state for total system</li> <li>• Full flexibility to custom design for application</li> <li>• Very low maintenance</li> <li>• Automatic electrolyte rebalancing</li> <li>• Little or no hydrogen vented</li> <li>• Can use trim cells for automatic voltage stabilization during charge/discharge</li> <li>• Trim cells can match array peak power point voltage (photo voltaic)</li> <li>• Long life system</li> <li>• Controlled current discharge if accidentally grounded or short circuited</li> </ul>
Operating Disadvantages:	<ul style="list-style-type: none"> <li>• Complex monitoring &amp; control of environment</li> <li>• Chill systems may be req.</li> <li>• Electrolyte agitation may be required</li> <li>• Difficult to determine system state of charge</li> <li>• Permanent damage from charge/discharge outside of specified ranges.</li> <li>• High current, rapid Discharge if grounded or shorted out</li> <li>• Water consumption req. Regular refills in multiple unit cells</li> <li>• Corrosive acid leak or spill hazard</li> </ul>	<ul style="list-style-type: none"> <li>• Unknown operating characteristics</li> <li>• Necessary to completely discharge system every 15-20 cycles</li> <li>• Contains Free chlorine gas</li> <li>• May have limited in/out switching times due to thermal effects</li> <li>• Requires a complex heat dissipation &amp; Refrigerator unit</li> <li>• Requires auxiliary pumps &amp; plumbing</li> </ul>		<ul style="list-style-type: none"> <li>• Unknown operating characteristics</li> <li>• Requires auxiliary pumps &amp; Plumbing</li> <li>• Relatively low energy density</li> </ul>